U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB-273 788

Source Assessment Pressed and Blown Glass Manufacturing Plants

Battelle Columbus Labs, Ohio

Prepared for

Industrial Environmental Research Lab, Research Triangle Park, N C

Jan 77

PB 273 788

EPA-600/2-77-005
JANUARY 1977

Environmental Protection Technology Series

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

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NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-77-005

2.

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE
SOURCE ASSESSMENT: PRESSED AND BLOWN GLASS MANUFACTURING PLANTS

5. REPORT DATE January 1977

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Battelle-Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

10. PROGRAM ELEMENT NO. 1AB015; ROAP 21AFA-013

11. CONTRACT/GRANT NO. 68-02-1323, Task 37

12. SPONSORING AGENCY NAME AND ADDRESS
EPA, Office of Research and Development
Industrial Environmental Research Laboratory
Research Triangle Park, NC 27711

13. TYPE OF REPORT AND PERIOD COVERED Task Final; 9/75-1/77

14. SPONSORING AGENCY CODE EPA-ORD 600/13

15. SUPPLEMENTARY NOTES Task officer for this report is Dale A. Denny, Mail Drop 62, 919/549-8411 Ext 2547. Earlier related reports are: EPA-650/2-75-019a and the EPA-600/2-76-032 series.

16. ABSTRACT

This report summarizes the results of a study to gather and analyze background information and technical data related to air emissions from glass manufacturers producing pressed and blown glassware. This includes all glassware except flat glass, glass containers, and fiber glass. The report covers emissions from three areas within the plant: raw materials preparation and handling, glass melting, and forming and finishing operations. Emissions from the melting furnace account for over 80 percent of the total plant emissions. The major pollutants are NO_x, SO_x, and submicron particulates consisting predominately ($\approx$80%) of mineral sulfates but can also include fluoride and borate compounds. NO_x has the largest emission factor (4.5 g/kg) with annual emissions of 57.5×10^9 g. In comparison with national emissions from stationary sources, NO_x emissions from glass melting furnaces contributes 0.17 percent of the total. The source severity is a measure of the potential environmental effect of air emissions and is the ratio of the maximum average ground level concentration compared to the primary ambient air quality standard for criteria pollutants. For this study source severity factors determined were largest for NO_x, SO_x, lead (PbO), and other particulates. Other emissions had a low severity factor ($\approx$0.01).

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Air Pollution	Dust	Air Pollution Control	13B	11G
Assessments	Minerals	Source Assessment	14B	08G
Glass Industry	Sulfates	Stationary Sources	11B	
Containers		Particulate	13D	
Nitrogen Oxides		Mineral Sulfates	07B	
Sulfur Oxides				

18. DISTRIBUTION STATEMENT Unlimited

19. SECURITY CLASS *(This Report)* Unclassified

20. SECURITY CLASS *(This page)* Unclassified

21. NO. OF PAGES 143

22. PRICE PCA07 MFA01

EPA Form 2220-1 (9-73)

EPA-600/2-77-005
January 1977

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Contract No. 68-02-1323, Task 37
ROAP No. 21AFA-013
Program Element No. 1AB015

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Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

PREFACE

The Industrial Environmental Research Laboratory (IERL) of EPA has the responsibility for insuring that air pollution control technology is available for stationary sources. If control technology is unavailable, inadequate, uneconomical, or socially unacceptable, then development of the needed control techniques is conducted by IERL. Control approaches considered include: process modifications, feedstock modifications, add-on control devices, and complete process substitution. The scale of control technology programs range from bench- to full-scale demonstration plants.

The Chemical Processes Section of IERL has the responsibility for developing control technology for a large number (> 500) of operations in the chemical and related industries. As in any technical program, the first step is to identify the unsolved problems. Each of the industries is to be examined in detail to determine if there is sufficient potential environmental risk to justify the development of control technology by IERL. This report contains the data necessary to make that decision for pressed and blown glass manufacturing plants.

Battelle's Columbus Laboratories was contracted by EPA to investigate the environmental impact of the pressed and blown glassware industry, which represents a source of emissions in accordance with EPA's responsibility as outlined above. Dr. J. Richard Schorr served as Program Manager for this study. Dr. Dale A. Denny served as EPA Project Monitor. The study was completed by IERL-RTP. Project responsibility was transferred to the Industrial Pollution Control Division of IERL-Cincinnati on October 15, 1975.

TABLE OF CONTENTS

Page

INTRODUCTION 1

SUMMARY 4

DESCRIPTION OF THE PRESSED AND BLOWN GLASSWARE INDUSTRY 11

General Process Description. 11

Plants and Location. 13

Shipment Value and Volume. 13

Glass Compositional Types. 13

Soda/Lime Silica Glasses. 15

Borosilicate Glasses. 16

Lead Glasses. 16

Opal Glasses. 16

Process Details. 17

Batch Handling. 19

Batch Composition 21

Melting and Fining. 21

Forming 25

Post-Forming and Finishing. 28

EMISSIONS 32

Raw-Materials Preparation and Handling 32

Glass Melting. 38

Nitrogen Oxides 38

Sulfur Oxides 42

Fluorides 44

Carbon Monoxide 44

Preceding page blank

TABLE OF CONTENTS
(Continued)

Page

Hydrocarbons 45

Particulates 45

Selenium 49

Other Emissions 50

Forming and Finishing 50

Forming 50

Treatment 52

Annealing 53

Decorating 53

Frosting of Light Bulbs 55

Acid Cleaning 55

Emission Characteristics 55

Raw Materials Preparation 55

Glass Melting 56

Forming and Finishing 56

Ground-Level Concentrations 57

Affected Population 68

CONTROL TECHNOLOGY 71

Raw-Materials Preparation 72

Emissions 72

Raw-Materials-Control Technology 73

Glass-Melting Operation 76

Emissions 76

Glass-Melting-Control Technology 78

Efficiency of Equipment 85

TABLE OF CONTENTS
(Continued)

Page

Forming and Finishing. 86

Forming Emissions 87

Forming and Finishing Control Technology. 87

Decorating. 87

Frosting of Electric Light Bulbs. 88

Acid Cleaning 88

Surface Treatment. 88

FUTURE PRODUCTION OF PRESSED AND BLOWN GLASSWARE. 90

REFERENCES. 91

APPENDIX A

Geographical Listing of Pressed-and-Blown Glass Plants. A-1

APPENDIX B

Emissions Data. B-1

APPENDIX C

Stack Heights from the Various Segments of Glassmaking Process. . C-1

APPENDIX D

State Listing of Total Emissions as of 1972 . . . . C-1

LIST OF TABLES

TABLE 1. GLASS INDUSTRY STATISTICS. 3

TABLE 2. AVERAGE UNCONTROLLED EMISSIONS OF MAJOR SPECIES FROM PRESSED AND BLOWN GLASSWARE PLANTS 6

TABLE 3. SOURCE SEVERITY FOR PRESSED AND BLOWN GLASS EMISSIONS. 9

LIST OF TABLES
(Continued)

Page

TABLE 4. PROPORTION OF INDUSTRY OUTPUT ACCOUNTED FOR BY THE CONSUMER, SCIENTIFIC, TECHNICAL, AND INDUSTRIAL GLASSWARE SEGMENTS OF SIC 3229. 14

TABLE 5. PARTICULATE EMISSIONS DURING RAW-MATERIAL PREPARATION AND HANDLING FOR PRESSED-AND-BLOWN GLASS. 36

TABLE 6. SPECIFICATION LIMITS FOR SEVERAL RAW MATERIALS USED IN PRESSED-AND-BLOWN GLASS MANUFACTURE(14). 37

TABLE 7. EMISSIONS FROM PRESSED AND BLOWN GLASS MELTING FURNACE OPERATIONS. 39

TABLE 8. EMISSIONS FROM THE FORMING AND FINISHING OPERATIONS FOR ALL PRESSED AND BLOWN GLASS 51

TABLE 9. EMISSIONS FROM THE ANNEALING OF PRESSED AND BLOWN GLASSWARE 54

TABLE 10. PARAMETERS OF A SODA/LIME GLASS-MELTING FURNACE (8.1 Gg ANNUAL PRODUCTION) REPRESENTATIVE OF THE PRESSED AND BLOWN INDUSTRY AS USED IN ATMOSPHERIC-DISPERSION CALCULATIONS. 58

TABLE 11. PARAMETERS OF A SODA/LIME GLASS-MELTING FURNACE (29.9 Gg ANNUAL PRODUCTION) REPRESENTATIVE OF THE PRESSED AND BLOWN INDUSTRY AS USED IN ATMOSPHERIC-DISPERSION CALCULATIONS. 59

TABLE 12. PARAMETERS OF A LEAD GLASS-MELTING FURNACE REPRESENTATIVE OF THE PRESSED AND BLOWN INDUSTRY AS USED IN ATMOSPHERIC-DISPERSION CALCULATIONS 60

TABLE 13. RELATIVE FREQUENCY OF ATMOSPHERIC STABILITIES(a). . . 64

TABLE 14. MAXIMUM POLLUTANT CONCENTRATIONS AND SOURCE SEVERITY FOR EMISSIONS FROM REPRESENTATIVE PRESSED AND BLOWN MELTING FURNACES. 65

TABLE 15. MAXIMUM AVERAGE GROUND-LEVEL CONCENTRATION (X_{max}) OF SELECTED AIR POLLUTANTS FROM REPRESENTATIVE MATERIALS HANDLING AND TREATMENT OPERATIONS 67

TABLE 16. GLASS-GRADE PARTICLE-SIZE SPECIFICATIONS FOR SAND, LIMESTONE, AND 10- AND 20-MESH DOLOMITE 74

TABLE 17. MAXIMUM USE TEMPERATURE FOR VARIOUS FABRIC-FILTER MATERIALS 82

LIST OF TABLES
(Continued)

Page

TABLE A-1. GEOGRAPHICAL LISTING OF THE 176 PRESSED AND BLOWN GLASS PLANTS. A-1

TABLE B-1. SUMMARY OF SOURCE TEST DATA FOR MATERIALS PREPARATION AND HANDLING(a) B-2

TABLE B-2. NO_X EMISSIONS FROM PRESSED AND BLOWN GLASSWARE FURNACES. B-4

TABLE B-3. SO_X EMISSIONS FROM PRESSED AND BLOWN GLASSWARE FURNACES. B-6

TABLE B-4. PARTICULATE MEISSIONS FROM PRESSED AND BLOW GLASSWARE FURNACES. B-8

TABLE B-5. CO EMISSIONS FROM PRESSED AND BLOW GLASSWARE. B-9

TABLE B-6. HC EMISSIONS FROM PRESSED AND BLOWN GLASSWARE B-11

TABLE B-7. HYDROCARBON EMISSIONS FROM FORMING PRESSED AND BLOWN GLASSWARE B-14

TABLE C-1. TYPICAL STACK HEIGHTS OF BATCH-HANDLING OPERATIONS FOR SODA/LIME GLASS C-1

TABLE C-2. TYPICAL STACK HEIGHTS FOR MELTING OPERATIONS OF GLASS FURNACES. C-2

TABLE C-3. TYPICAL STACK HEIGHTS FOR FORMING OPERATIONS. C-3

TABLE C-4. TYPICAL STACK HEIGHTS FOR ANNEALING OPERATIONS OF BOROSILICATE GLASS. C-5

TABLE C-5. TYPICAL STACK HEIGHTS FOR DECORATING OPERATIONS OF SODA/LIME GLASS C-6

TABLE C-6. TYPICAL STACK HEIGHTS FOR TREATMENT OPERATIONS OF SODA/LIME GLASS C-7

TABLE D-1. STATE LISTING OF TOTAL EMISSIONS AS OF 1972 . . . . . D-1

TABLE D-2. (CONTINUED) D-2

TABLE D-3. (CONTINUED) D-3

TABLE E-1. CONVERSION FACTORS. E-1

LIST OF FIGURES

Page

FIGURE 1. PROCESS FLOW DIAGRAM. 12

FIGURE 2. PROCESS FLOW DIAGRAM: SIC 3229, PRESSED-AND-BLOWN GLASS (EXCLUDING TEXTILE FIBERS). 18

FIGURE 3. PROCESS FLOW DIAGRAM OF A TYPICAL BATCH PLANT(9). . . 20

FIGURE 4. ILLUSTRATIVE SKETCH OF A CONTINUOUS TANK-TYPE OF SIDE-PORT REFENERATIVE-MELTING FURNACE(3) 23

FIGURE 5. THE CORNING RIBBON MACHINE(2) 26

FIGURE 6. TYPICAL POINTS OF PARTICULATE EMISSION FROM RAW-MATERIALS HANDLING 33

FIGURE 7. NO_X EMISSIONS FROM FLINT GLASS-CONTAINER FURNACE(18). 41

FIGURE 8. PARTICULATE EMISSIONS SHOWN ARE LINEAR WITH THE RECIPROCAL OF BRIDGEWALL TEMPERATURE. 47

FIGURE 9. PARTICULATE EMISSIONS FOR GLASSES AS A FUNCTION OF PULL RATE 48

FIGURE 10. ILLUSTRATION DEPICTING CALCULATION OF AREA WHICH CONTAINS THE AFFECTED POPULATION 69

LIST OF SYMBOLS

Symbol	Definition
AAQS	Ambient air quality standard
A, B, C, D, E, F	Atmospheric stability classes
a, b, c, d, e, f	Constants in dispersion equations
A_R	The ratio $Q/ac\pi u$
B_R	The ratio $-H^2/2c^2$
CI	Confidence Interval
D_i	Inside stack diameter
e	Natural logarithm base
H	Effective stack height
h	Physical stack height
ΔH	Plume rise
k	"Student t" test variable
m	Number of samples
N_i	Sample value
p	Atmospheric pressure
Q	Mass emission rate
R	Downwind dispersion distance from source of emission release
s	Sample standard deviation
S	Source severity, ratio $\overline{X}_{max}$/AAQS
T_a	Ambient temperature
T_s	Stack gas temperature
t_o	Instantaneous averaging time of 3 minutes
t	Averaging time
TLV	Threshold limit value
u	National average wind speed
v_s	Stack gas exit velocity
R	Horizontal distance from centerline of dispersion

LIST OF SYMBOLS (Continued)

Symbol	Definition
μ	Sample mean
π	3.14
σ	Standard deviation
X	Downwind ground level concentration at reference coordinate x and y with emission height of H
$\bar{X}$	Time average ground level concentration of an emission
X_{max}	Instantaneous maximum ground level concentration
$\bar{X}_{max}$	Time average maximum ground level concentration

SECTION I

INTRODUCTION

Air emissions released in the manufacture of pressed and blown glassware have been examined in this study. This report describes the nature of the pressed and blown glass industry, the nature of air emissions from this industry and their environmental impact, the control technology employed, and the future growth of this industry segment. Pressed and blown glassware is one of three segments of the glass industry (glass containers, flat glass, and pressed-and-blown glassware). Each segment is defined by a Standard Industrial Classification (SIC) number, as used by the Department of Commerce. Pressed-and-blown glassware is designated by SIC 3229 and includes all glassware not classified under SIC 3221 or SIC 3211. This industry segment is very diversified and includes products such as:

- Table, kitchen, art, and novelty glassware
- Lighting and electronic glassware
- Scientific, technical, and other glassware
- Textile glass fibers.

Industry shipments in 1973 had a value of $1.12 billion, which was about 25 percent of the glass industry total. This has increased to 1.3 billion by 1974.

Glass containers are designated by SIC 3221 and include the manufacture of glass containers for food, beverages, medicines, toiletries, and cosmetics. It includes both narrow-neck and wide-mouth containers. Shipments in this segment have grown at an average rate of about 3.5 percent since 1971. Industry shipments in 1973 had a value of $2.3 billion, or about 51 percent of the glass industry total.

Flat glass is designated by SIC 3211. This includes both the manufacture of flat glass and some fabrication of flat glass into a tempered or laminated-glass product. Flat glass products include: window glass, plate glass, wire glass, tempered glass, and laminated glass. These products are consumed primarily by the automotive and construction industries. Value of shipments in 1973 was $1.1 billion, which was 24 percent of the glass industry total.

Table 1 lists some 1973 statistics on the three segments of the glass industry. It shows that over 154,000 people produced merchandise valued at over $4.5 billion.* Only 9 percent of the glass product shipments are produced by the pressed and blown segment of the glass industry.

Separate Source Assessment Documents have been prepared for the flat glass and container glass segments. This report deals only with pressed and blown glassware exclusive of fibrous glass; however, many of the same emissions and control technology are also found in the other glass industry segments. The report delineates the various emission points, identifies the type and quantity of emissions, and describes the characteristics of the air pollutants found. Mass emissions for criteria pollutants (particulates, NO_x, SO_x, and CO and hydrocarbons) from pressed and blown glassware plants are compared with national emissions from all stationary sources. The theoretical maximum time average, ground-level concentrations due to emissions from a pressed and blown glass plant are compared to the corresponding ambient air-quality standards. Control technology which is being used or could be applicable to the manufacture of glass products is also discussed. The manufacturing operations for glass production are grouped into three categories:

- Preparation of raw materials
- Glass melting
- Forming and finishing

Emissions and control technology for each of these three areas are presented.

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* References are listed on Page 92.

TABLE 1. GLASS-INDUSTRY STATISTICS [(a)]

SIC	Industry Segment	1973 Employees, (10^3)	1973 Value of Shipments, ($ Million)	1973 Shipments [(b)], (Tg x 10^6)
3221	Glass Containers	77.8	2,316	11.32
3211	Flat Glass	26.3	1,118	3.12
3229	Pressed-and-Blown Glass [(c)]	50.0	1,120	1.57
	Total	154.1	4,554	16.01

(a) Source: Department of Commerce and References 1 and 2.

(b) See Appendix E for conversion factors.

(c) Excludes textile fibers.

SECTION II

SUMMARY

This document describes a study of air emissions released during the production of pressed and blown glassware. The industry is defined by Standard Industrial Classification (SIC) No. 3229, except for glass fiber production. The study encompasses the preparation of raw materials at the plant site, the production of molten glass in a furnace, the forming of glass articles, and certain post-forming operations necessary to manufacture the products of this diverse industry.

The pressed and blown glass industry in the United States produced an estimated 1.46 Tg* (1.614 million tons) of salable product in 1974. Of that total, about 77 percent (1.12 Tg) was soda-lime glass; 11 percent (0.15 Tg) was borosilicate glass; 5 percent (0.01 Tg) was lead glass; and about 7 percent (0.10 Tg) was opal glass. In 1974, the industry segment consisted of 110 manufacturers operating 176 plants. Geographically, these plants were concentrated in or about the North-Central region of the country, primarily in New York, Illinois, Indiana, Ohio, Pennsylvania, New Jersey, and West Virginia. Pressed and blown glassware was produced in 28 states. The average county population density at a plant site was estimated to be 356 people/km^2.

Manufacturing Technology

In a glass-manufacturing process, raw materials (e.g., sand, soda ash, limestone) are uniformly mixed and these loose materials are transported to a furnace where they are melted at elevated temperatures (> 1500 C) into a homogeneous mass. More than 90 percent of the glass is made in fossil fuel-fired furnaces where energy is predominately transferred to the glass by radiation from a flame or reradiation from the refractory chamber containing molten glass. Molten glass is kept at elevated temperatures until it is of a quality (bubble-free) sufficient for making the desired product. The glass is then cooled to approximately 1300 C, and removed from the furnace, either continuously or cut into "gobs". The molten glass is fed to machines, where it is formed into desired shapes which then undergo additional finishing operations. The type of finishing operation depends upon the type of product being manufactured. Essentially, all glass products go through an annealing furnace for removal of residual stresses. The temperatures in annealing range from about 590 to 650 C.

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* Tg = 10^{12} gram. Metric prefixes and other conversion factors are given in Appendix E, Page E-1.

Emissions

Emissions were examined from three areas within the glass manufacturing plant: (1) raw-materials preparation and handling, (2) glass melting and (3) forming and finishing. The largest emissions occur from the glass-melting operation.

Manufacturing Plant

Table 2 summarizes the average emissions of the major species determined for this study. It should be noted that no one glass plant will have all of these emissions, because they are dependent upon both the type of glass produced and the type of process equipment employed. As can be seen, 98 percent of the plant emissions come from the glass melting furnace. The major species (over 93%) are NO_x, SO_x, and particulates. Furnace stack heights average 19 m when ejection air is used and 44 m for natural draft. Stack heights are summarized in Appendix C.

Total Industry

Nitrogen oxides constitute the second largest emission source (4.25 g/kg ± 43%). Total annual emissions are estimated to be 12.6 Gg which amounts to approximately 0.109 percent of the 1972 NO_2 National emissions from all stationary sources.

Sulfur oxide emissions can result from either sulfur compounds added in the batch or from sulfur in the fossil fuel. They are the third largest emission source (2.80 g/kg ± 62%). Total annual emissions are estimated to be 8.3 Gg which amounts to approximately 0.130 percent of the 1972 National emissions of SO_x from all stationary sources.

TABLE 2. AVERAGE UNCONTROLLED EMISSIONS OF MAJOR SPECIES FROM PRESSED AND BLOWN GLASSWARE PLANTS(a)

	EMISSION SPECIES								
	NO_x	SO_x	Particulates	CO	Hydrocarbons	Fluorides	Selenium	HCl	NH_3
EMISSION FACTOR, g/kg(b)									
(1) Raw Materials	0	0	1.91±100%	0	0	0	0	0	0
(2) Glass Melting	4.25±43%	2.80±62%	8.7±60%	0.1±100%	0.15±53%	10±100%	0.002±100%	0	0
(3) Form/Finish									
Forming	0	0	0	0	0.06±100%	0	0	0	0
Treatment	0	0	0.05±100%	0	0	0	0	0.02±100%	0
Annealing	0.02±100%	0	Trace(c)	Trace(c)	Trace(c)	0	0	0	0
Decorating	0	0	0	0	4.5±100%	0	0	0	0
Frosting	0	0	0	0	0	0.96±100%	0	0	0.44±100%
Acid Clean	0	0	0	0	0	0.18±100%	0	0	0
TOTAL ANNUAL EMISSIONS, Mg									
(1) Raw Materials	0	0	6	0	0	0	0	0	0
(2) Glass Melting	12,622	8,316	25,839	297	445	3000	2	0	0
(3) Form/Finish	48	0	21	7	638	103	0	7	20
Forming	0	0	0	0	178	0	0	0	0
Treatment	0	0	17	0	0	0	0	7	0
Annealing	48	0	4	7	4	0	0	0	0
Decorating	0	0	0	0	456	0	0	0	0
Frosting	0	0	0	0	0	87	0	0	20
Acid Clean	0	0	0	0	0	16	0	0	0

(a) Based on 3.37 Tg of raw materials processed to melt 2.97 Tg of glass.

(b) Table 8 gives a breakdown of emission factors for various glass types.

(c) Trace is less than 0.01 g/kg.

Particulate emissions from the melting furnace are the highest emission source (8.70 g/kg ± 60%) of the three major species. Total annual emissions are estimated to be 25.8 Gg, which represents approximately 0.020% of National emissions from all stationary sources. Fluorides can be emitted as both gases and particulates at a rate taken as 10 g/kg ± 100%. Total annual emissions are estimated to be 3.0 Gg.

Carbon monoxide has an emission factor of 0.1 g/kg ± 100% with total annual emissions of 0.3 Gg. The emission factor for hydrocarbons is 0.15 g/kg ± 53% with total annual emissions of 0.4 Gg. These contribute 0.002 and 0.001 percent, respectively, to the National emissions from all stationary sources. Finally, the emissions factor for selenium is 2 mg/kg ± 100% with total annual emissions of 0.002 Gg.

Emissions from raw materials preparation and handling can give rise to some particulate emissions, primarily from dust generated during discharging, conveying, crushing, and mixing operations. The composition of these emissions is the same as that of the raw materials used. The average emission factor is 1.91 g/kg ± 100%. Total annual emissions are estimated to be 0.006 Gg or 0.0004 percent of the National particulate emissions from all stationary sources. A common practice for the industry is the employment of controls (primarily filter bags) in dust generating areas.

Many different processes are used in the forming and finishing operations, depending on the type of product being manufactured. Emissions from the more common operations are identified in Table 2. These emissions consist of hydrocarbons emitted from the forming operation (0.06 g/kg); tin oxide, hydrated tin chloride particulates (0.05 g/kg), and HCl (0.02 g/kg) emitted from surface treatment operations; combustion products emitted from gas-fired annealing lehrs; and hydrocarbon (4.5 g/kg) emitted from decorating operations that are used by about 10% of the industry. Additionally, HF and NH_3 are emitted during frosting of light bulbs and HF is emitted during acid cleaning of some glass products. The emissions from all these areas constitute less than 2% of the total emissions by the industry.

Control Technology

Emissions from furnaces melting soda lime glass are generally not controlled by add-on equipment. More often, the particulate emissions from furnaces melting other glass types will be controlled. This practice varies with geographical location. Frequently, emission standards can be met without the use of control equipment (e.g., baghouses and electrostatic precipitators).

Source Severity

Impacts of these emissions are directly related to the ambient concentrations the emissions create at ground level. Atmospheric dispersion calculations have been made to calculate the theoretical maximum average ground-level concentrations ($\overline{X}_{max}$) due to emissions from melting, materials-handling, and surface treatment. The results of these calculations are presented in Table 3.

The source severity factor, S, has also been used to describe the impact of the emissions. For those pollutants which have an ambient air-quality standard (AAQS), S is the ratio of $\overline{X}_{max}$ to the primary AAQS. In cases where no AAQS has been established, S is based upon the Threshold Limit Value (TLV) through the following equation which includes a factor for correcting the TLV to a 24-hour day (8/24) and a safety factor (1/100).

$$S = \frac{\overline{X}_{max}}{TLV\ (8/24)\ (1/100)}$$

Results of the Source severity factor calculations also appear in Table 3. The highest severity factor (0.89) is produced by fluoride emissions from lead glass melting operations.

A third measure of the impact of the plant emissions is given by the Affected Population. This measure is defined as the population around the plant who are exposed to a source severity factor greater than 1.0. Computations of the affected population showed that all sources were less than 1.0.

TABLE 3. SOURCE SEVERITY FOR PRESSED AND BLOWN GLASS EMISSIONS(a)

Source Pollutant	Primary Ambient Air-Quality Standard		Theoretical Maximum Average Ground-Level Concentration, $\bar{X}_{max}$, Mg/m³			Severity Factor		
	µg/m³	Averaging Time, hr	Soda/Lime		Lead	Soda/Lime		Lead
Melting Furnace (Glass) **Annual Production (Gg)**			8.1	29.9	4.6	8.1	29.9	4.6
NO_x	100	24	7.3	17.7	-	0.073	0.18	-
SO_x	365	24	4.5	11.1	-	0.012	0.030	-
Particulates	260	24	8.8	21.9	10.7	0.034	0.084	0.041
CO	$4x10^4$	8	0.23	0.48	-	$5.7x10^{-6}$	$1.2x10^{-5}$	-
Hydrocarbons	160	3	0.36	0.88	-	$2.3x10^{-3}$	$5.5x10^{-3}$	-
Selenium	0.67(b)	24	$3.4x10^{-3}$	$8.4x10^{-3}$	$4.1x10^{-3}$	$5.0x10^{-3}$	0.013	$2.2x10^{-3}$
Fluoride	8.33(b)	24	-	-	7.4	-	-	0.89
Materials Handling								
Particulates	260	24		1.96			0.0076	
Surface Treatment								
Hydrogen Chloride	23(b)	24		4.11			0.176	
Titanium Chloride	33(b)	24		4.11			0.123	

(a) Other severity factors including those for tin particulates and ammonia were quite low.

(b) These concentrations are not air quality standards but were developed from threshold limit values and were used in testing source severity.

Future Growth

The pressed and blown glass industry produces a diverse and always changing spectrum of glass products. Shipments are expected to increase at a rate of 3 to 4 percent per year, and emissions would be expected to increase proportionally. All-electric furnaces have become economically attractive for melting some glasses and these furnaces are virtually pollution free. A continued trend in this direction could offset emissions due to growth of the industry. On the other hand, the general unavailability of natural gas has resulted in increased use of oil. The actual effect of conversion from gas to oil firing on emission rates is not known, but would be expected to increase emissions, all other operating parameters being the same.

SECTION III

DESCRIPTION OF THE PRESSED AND BLOWN GLASSWARE INDUSTRY

This section describes in general terms the process steps used in the manufacture of pressed and blown glassware and presents certain statistical information pertinent to the pressed and blown glassware industry described by the Department of Commerce Standard Industrial Classification (SIC) 3229. Textile glass fibers, which are a part of this classification, have been excluded from this report.

General Process Description

The pressed and blown glassware industry, as represented by SIC 3229, essentially comprises all industrial establishments primarily engaged in manufacturing glassware which is pressed, blown or shaped from glass produced in the same establishment. It consists of every type of glass or glassware except flat glass (SIC 3211) and glass containers (SIC 3221). Establishments include those manufacturing: textile glass fibers; lighting, electronic, and technical ware; machine made and handmade table, kitchen and art-ware glass products. Textile fibers which are part of the Department of Commerce classification SIC 3229 are excluded from discussion in this report.

Figure 1 is a process-flow diagram which generally depicts the flow of materials through the glass manufacturing process. It can generally be categorized into four steps: batch handling, melting and fining, forming, and postforming. These steps are discussed in detail later in this section.

Basically, the manufacture of glass products entails the melting of a mixture of raw materials which has been prepared in the batch handling step, so as to minimize segregation and impurities in the batch. Cullet (scrap glass) is also added in this step. In the glass melter, materials are melted, molten glass fined (residual trapped gases removed), and the temperature of the glass lowered so that it can be handled in the forming operation. Glass passes from the melter to the forming equipment via the forehearth, a relatively shallow, narrow refractory channel having a refractory roof and individual heating and cooling systems for controlling glass temperature. Glass is removed from the melter either in small lots or continuously, after which the molten glass is pressed, blown, drawn, or cast into shape, depending upon the product. These formed

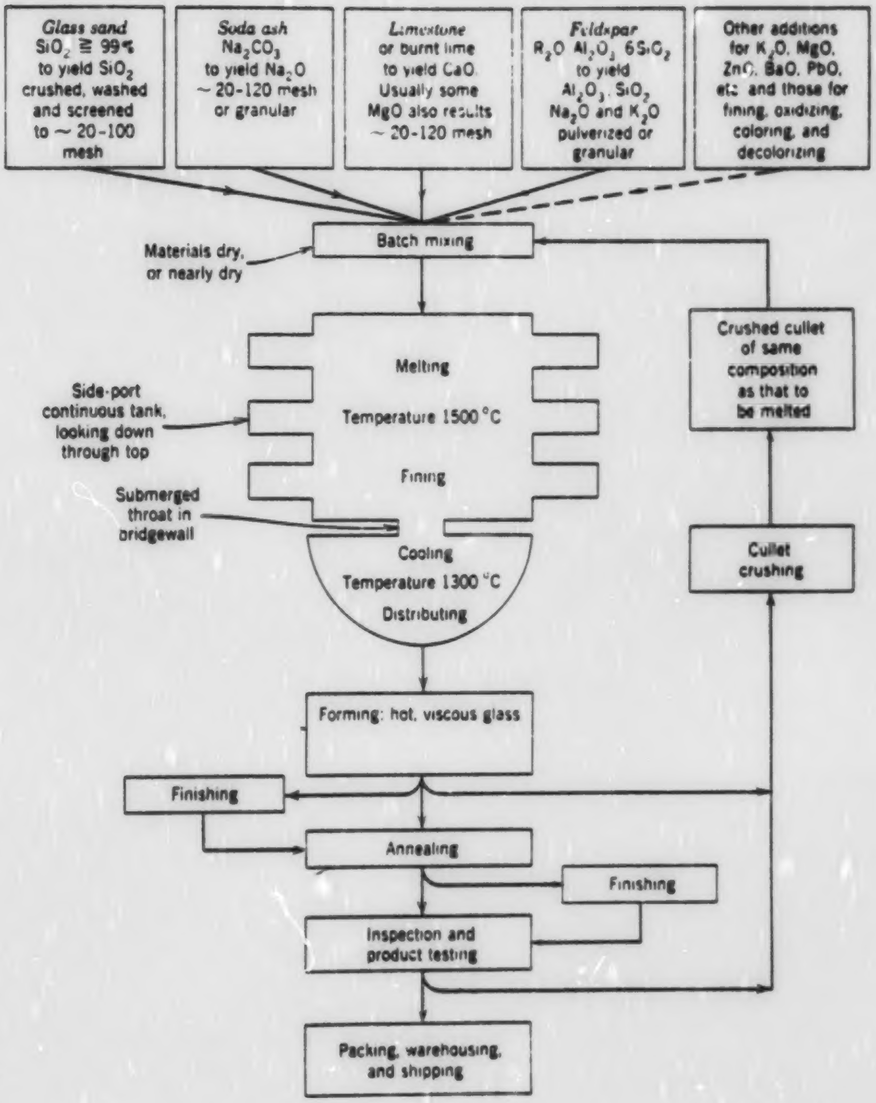
Glass sand
$SiO_2 \geqq 99\%$
to yield SiO_2
crushed, washed and screened to ~ 20-100 mesh
Soda ash
Na_2CO_3
to yield Na_2O
~ 20-120 mesh or granular
Limestone
or burnt lime to yield CaO. Usually some MgO also results
~ 20-120 mesh
Feldspar
$R_2O \cdot Al_2O_3 \cdot 6SiO_2$
to yield
Al_2O_3, SiO_2, Na_2O and K_2O
pulverized or granular
Other additions for K_2O, MgO, ZnO, BaO, PbO, etc. and those for fining, oxidizing, coloring, and decolorizing
Batch mixing
Materials dry, or nearly dry
Melting
Temperature 1500 °C
Fining
Side-port continuous tank, looking down through top
Submerged throat in bridgewall
Cooling
Temperature 1300 °C
Distributing
Crushed cullet of same composition as that to be melted
Cullet crushing
Forming: hot, viscous glass
Finishing
Annealing
Finishing
Inspection and product testing
Packing, warehousing, and shipping

FIGURE 1. PROCESS FLOW DIAGRAM (2)

glass products may then go through a variety of post-forming steps, one of which is annealing (the removal of residual stresses through a controlled, uniform cooling cycle). Other post-forming steps include surface treatment, decoration, firepolishing, etching, cutting, and sealing.

Plants and Locations

According to information gathered from the Department of Commerce 1972 Census of Manufacturers,(2) there were 158 establishments manufactured $100,000 or more of pressed and blown glassware shipments in 1972. By 1975, the number of establishments had increased by 163. These 163 plants were operated by 110 manufacturers. The top 50 companies produced nearly 98 percent of the total of the pressed and blown glassware shipped. Approximately 44 plants produced handmade pressed and blown glassware almost exclusively.

The industry is concentrated in or about the North Central region of the United States, primarily New York, Pennsylvania, West Virginia, Ohio, Indiana, and Illinois. Additionally, plants are located in 22 other states, as shown in Appendix A.

Shipment Value and Volume

Table 4 gives estimated 1974 output data for the pressed and blown glass industry. As can be seen, each of the three product types listed comprises a significant portion of this industry. Handmade glassware utilizes significantly different manufacturing methods and is listed separately.

The value of shipments for 1974 was estimated to be $1307 million as compared with $1108 million in 1971, or an increase of 18 percent. Shipments from the many industry segments were difficult to estimate because of the many different product types and methods of reporting. The estimated 1974 output, approximately 2.7 Tg (2197 million tons) of glass, was melted to produce industry shipments of 1.3 Tg (1.4 million tons) of glass. Thus, about 1.4 Tg of glass was recycled as cullet.

Glass Compositional Types

Most commercial glasses (> 90%) are composed of SiO_2 as the major ingredient (> 55%) with other inorganic oxides added to achieve specific modifications

TABLE 4. PROPORTION OF INDUSTRY OUTPUT ACCOUNTED FOR BY THE CONSUMER, SCIENTIFIC, TECHNICAL, AND INDUSTRIAL GLASSWARE SEGMENTS OF SIC 3229

Process and Major Products	SIC	Percent of 1974	
		Shipments Value	Shipments Volume
Table, Kitchen, and Art Ware			
Machine Made	(32291)	35.0	57
Hand Made		6.5	3
Lighting and Electronic	(32292)	30.4	23
Scientific and Industrial	(32294)	28.1	17
Total Industry	(Percent)	100	100
	(Actual)	$1,306,529,000	1.46 Tg (1,613,600 Tons)[a]

(a) Shipments volume estimated on the basis of shipment values of $500; $1,800; $1,075; and $1300; respectively, for the three SIC categories.

Source: Current Industrial Reports, MA-32E for shipment value in SIC 32291, 32292, and 32294.

in glass properties. The addition of alkali oxides (especially Na_2O) reduces the high viscosity inherent in SiO_2 glass (fluxes the glass) to bring manufacturing into the range of industrially accessible temperatures and refractories. Calcium oxide is an inexpensive yet effective additive for improving the chemical durability of the glass. Boric oxide is also considered a flux, but it does not raise the coefficient of thermal expansion as much as alkali oxides (low thermal expansion is important to thermal shock resistance). Additionally, lead oxide is a good flux which does not reduce electrical resistivity as much as the alkali oxides. Lead oxide glasses have a high refractive index and a capability for X-ray and gamma-ray radiation absorption. Compositionally, the four important categories of glasses manufactured by the pressed and blown industry and the relative percent of total production by weight in each category are:

		Estimated Percentage of Production
(1)	Soda/lime	77
(2)	Borosilicate	11
(3)	Lead silicate	5
(4)	Opal	7

Soda/Lime-Silica Glasses

For the soda-lime-silica glasses, which represent the majority of pressed and blown tonnage, the basic batch ingredients are sand (silica), soda ash (sodium carbonate), limestone (calcium carbonate) and feldspar (a silicous mineral used as a source of alumina and alkali). Additionally, the batch will contain minor ingredients which promote fining, act as decolorizer and a colorant or impart other specific properties. The raw materials are indigenous to most areas and are inexpensive.

In the soda-lime-silica-based system, the optimum glass with respect to cost, durability, and ease of manufacture has an approximate composition of 72 percent silica, 15 percent soda, 10 percent lime and magnesia, 2 percent alumina and 1 percent miscellaneous oxides. Magnesia is used primarily to reduce cost by the substitution of dolomitic limestone for calcite as a raw material. The alumina improves chemical durability and decreases the problem of crystallization during forming.(2, 3) Primary pressed and blown products employing this type of glass are incandescent lamps, tubing, and tableware.

Borosilicate Glasses

Borosilicate glass batches are also predominantly sand (silica) but boric oxide replaces much of the alkali content which is characteristic of soda lime-silica batches. The calcium plus magnesium oxide content is very low. A few percent of alumina and zero to a few percent of barium oxide are included. A higher melting temperature is required for borosilicate glasses than for soda-lime and volatility from the melt for borosilicate glasses is much higher. The compositional ranges of typical commercial borosilicates are: 70-82 percent silica, 2-7.5 percent magnesia plus calcia, and 0-2.5 percent baria.(3)

The borosilicate glasses have excellent chemical durability and electrical properties and their low thermal expansion yields a product having high resistance to thermal shock. These combined properties make them ideal for demanding industrial and domestic use such as chemical laboratory ware, cookware, pharmaceutical ware, and for some lens reflectors and lamp envelopes. Pyrex®, produced by Corning Glass Works, and Kimax^R, produced by the Kimble Division of Owens Illinois, Inc., are examples of products made from borosilicate glasses.

Lead Glasses

These glasses are composed basically of silica and lead oxide. In addition, most contain significant amounts of alkali oxide. The compositional range of typical commercial lead glasses is: 35-70 percent silica, 12-60 percent lead oxide, 4-8 percent sodium oxide, 5-10 percent potassium oxide, and 0.5-2.0 percent alumina.(3)

The lead glasses are characterized by high electrical resistivity, high refractive index and slow rate of increase in viscosity with decrease in temperature. This viscosity characteristic makes them particularly well suited to hand fabrication. Lead glasses are used in high-quality art glass and tableware; for special electrical applications; optical glasses; fluorescent lamp envelopes; and X-ray, gamma-ray, and neutron radiation shielding windows.

Opal Glasses

Opal glasses are translucent and may be colored. Commercial products of opal glass include lighting globes, ointment jars, dinner ware, and wall paneling. The batch composition of common commercial opal glasses is basically similar to soda-lime glass but with modifications and additions. The alumina content is higher, lime lower, and opacifiers are added such as fluorides or phosphates plus other minor ingredients.

The translucency or opacity of opal glasses is produced by multiple scattering of light inside the glass. This scattering is achieved by the precipitation of crystals (or an immiscible amorphous phase) with an index of refraction different from that of the base glass. The degree of opacity is determined by the difference in refractive index between the base glass and dispersed crystal and by the number and size of the crystals. The amount of the opacifying phase is a minor percent of the total glass. Time-temperature relations for the forming, cooling, or heat-treating of opal glasses are critical because they determine the number and size of the dispersed phase and the resulting degree of opacification.

Commercial opal glasses commonly employ fluorine additions to yeild opacifying crystals of sodium or calcium fluoride. Typical commercial compositions are:(4)

Ingredient	Glass Jar Weight Percent	Illumination Glass Weight Percent
SiO_2	71.2	59.0
Al_2O_3	7.3	8.9
CaO	4.8	4.6
MgO		2.0
Na_2O	12.2	7.5
K_2O	2.0	
F_2	4.2	5.0
ZnO		12.0
PbO		3.0

Process Details

Figure 2 is a process flow diagram which generally depicts the flow of materials through plants producing glassware in the pressed and blown glass industry. All products produced in this industry undergo generally similar batch handling and melting and fining procedures, but the forming and post-forming operations differ widely in the typical operations listed for each five-digit SIC code indicate. Glass produced within SIC's 32292 and 32294 (Lighting, Electronic and Technical Ware) typically undergoes a variety of post-forming operations. Additional information about the processes shown in Figure 2 is given in subsequent discussions of the processing steps.

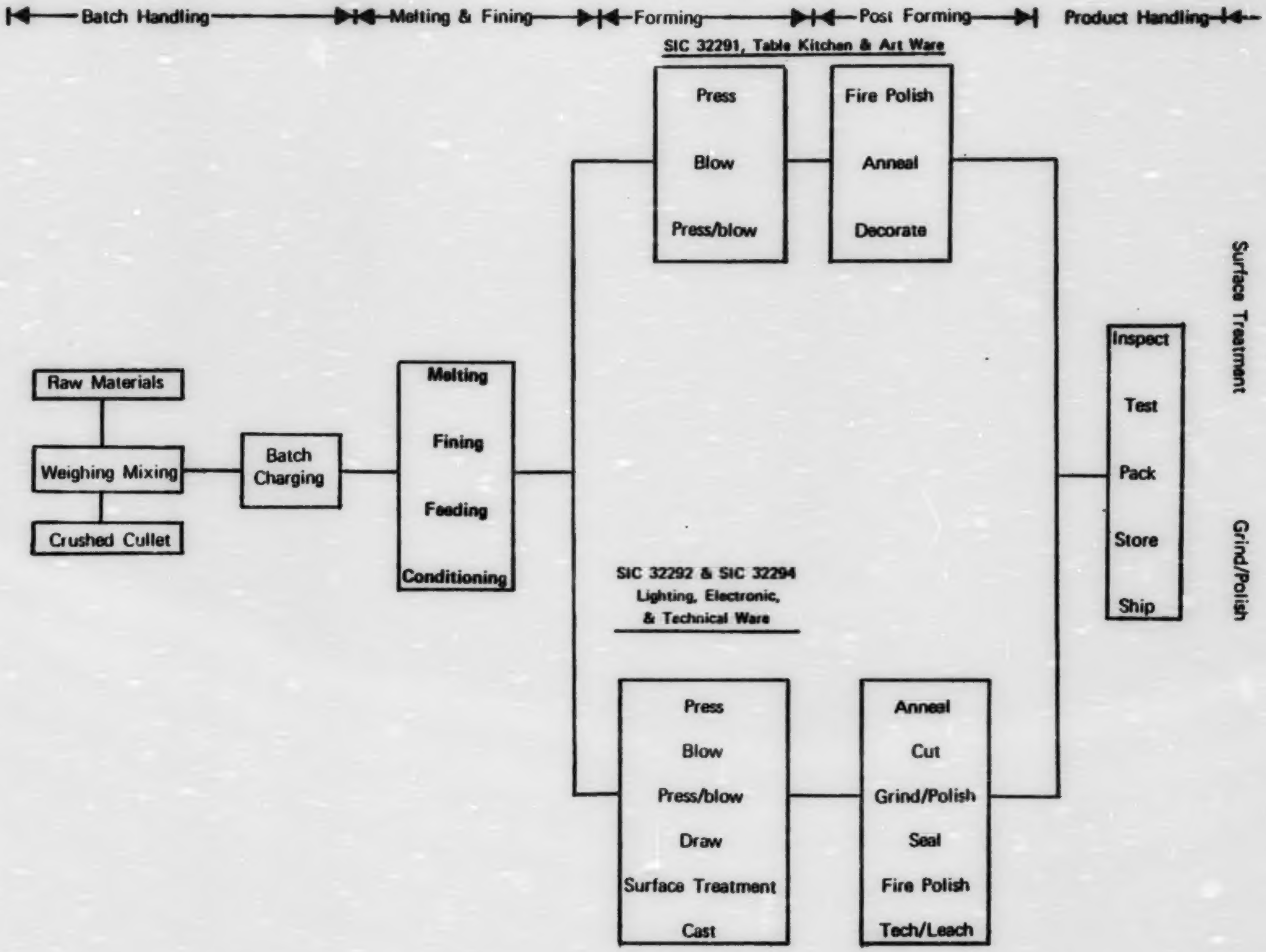
Batch Handling
Melting & Fining
Forming
Post Forming
Product Handling
SIC 32291, Table Kitchen & Art Ware
Raw Materials
Weighing Mixing
Crushed Cullet
Batch Charging
Melting
Fining
Feeding
Conditioning
Press
Blow
Press/blow
Fire Polish
Anneal
Decorate
SIC 32292 & SIC 32294 Lighting, Electronic, & Technical Ware
Press
Blow
Press/blow
Draw
Surface Treatment
Cast
Anneal
Cut
Grind/Polish
Seal
Fire Polish
Tech/Leach
Inspect
Test
Pack
Store
Ship
Surface Treatment
Grind/Polish

FIGURE 2. PROCESS FLOW DIAGRAM: SIC 3229, PRESSED-AND-BLOWN GLASS (EXCLUDING TEXTILE FIBERS)

Batch Handling

The function of the batch-handling operation is to prepare and feed to the melting furnace a batch which is both chemically and physically uniform in composition. Control of the composition, impurity level, size, and moisture content of the raw materials is important. Cullet (scrap glass) collected from the plant or sometimes purchased, is added in varying amounts, usually between 10 and 50 percent, to the batch.(4) The quantity added depends primarily on its availability. In some processes, large amounts of cullet are produced (e.g., manufacture of lamps). Cullet is crushed and either mixed with the raw materials or added later. Each of the raw materials is carefully weighed, mixed together, and conveyed to the batch chargers. Care must be taken so that segregation of a uniformly mixed batch does not occur.

A large plant operating a continuous machine forming process, may utilize a highly automated process for raw material mixing and conveying housed in a structure termed a "batch house". A flow diagram of a typical batch house is shown in Figure 3. In most (> 80%) batch houses, the storage bins are located on top, with the weigh hoppers and mixers located below them to make use of gravity flow. Major raw materials and cullet (broken scrap glass) are conveyed from railroad hopper cars or hopper trucks by a combination of screw conveyors, belt conveyors, and bucket elevators, or by pneumatic conveyors to the elevated storage bins. Minor ingredients are usually delivered to the plant in paper bags or cardboard drums and transferred by hand to small bins. Materials are gravity fed from the storage bins into weigh hoppers and then transported by transverse belts or bucket elevators into a mixer. Cullet is crushed to a desired size (usually between 0.5 and 2.0 cm).

After mixing, the glass batch is transferred to a charging bin located next to the glass-melting furnace or into a batch-storage bin, depending upon the design of the batch-handling system. Positive displacement or vibratory feeders at the bottom of the bins feed the materials to the glass-melting furnace chargers. Cullet may be added to the batch in the mixer, while the batch is being transferred, or charged separately to the melting furnace.(4) Batch is fed into the melter in either a dry or moist state. Many companies add two to four percent water to the dry batch to help prevent segregation during transport of the batch, to minimize dust problems in the melter, and to avoid carryover of dust into the regenerators.

The various handling and mixing operations are a source of particulate emissions which are similar (same materials, same processes) are those in other industries.(5, 6) Because of environmental and economic incentives, essentially

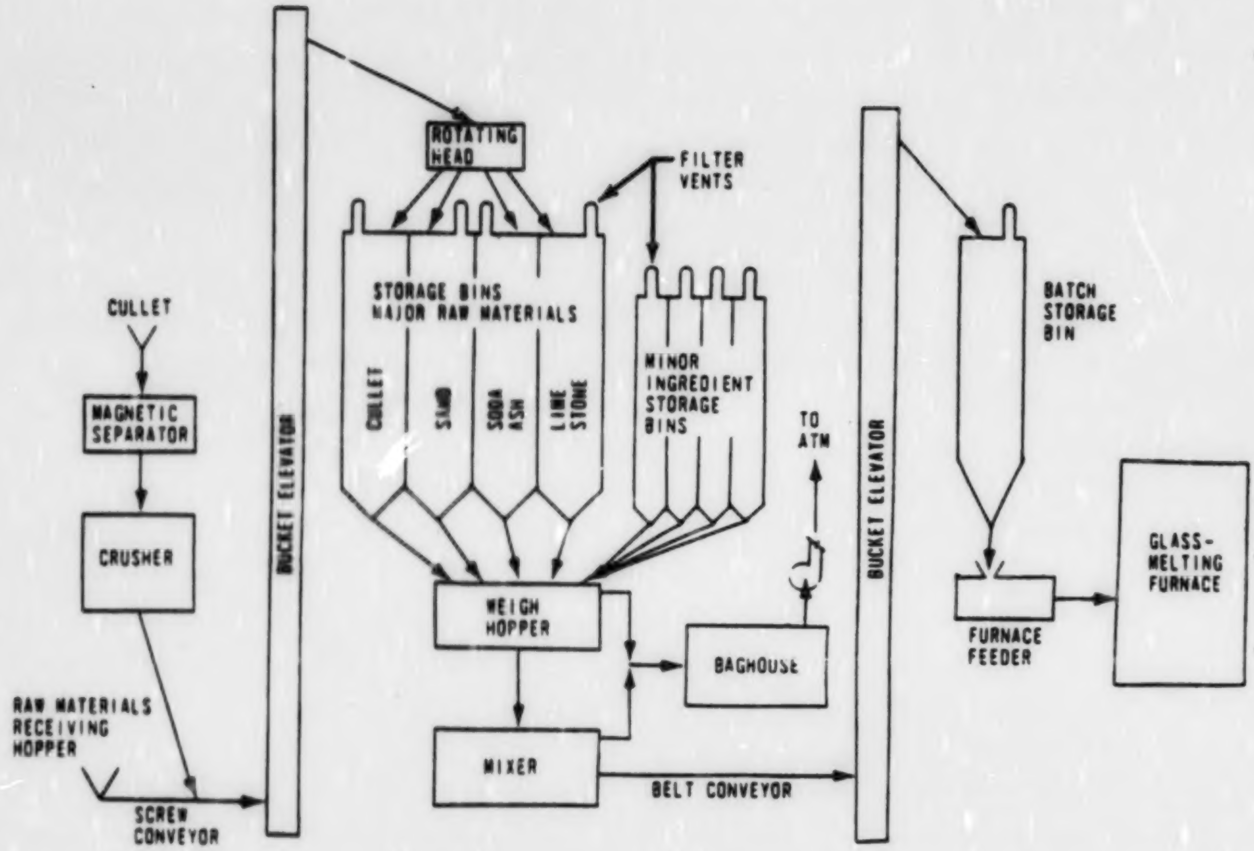
ROTATING HEAD
FILTER VENTS
CULLET
MAGNETIC SEPARATOR
CRUSHER
BUCKET ELEVATOR
STORAGE BINS MAJOR RAW MATERIALS
CULLET
SAND
SODA ASH
LIME STONE
MINOR INGREDIENT STORAGE BINS
TO ATM
WEIGH HOPPER
BAGHOUSE
MIXER
BELT CONVEYOR
RAW MATERIALS RECEIVING HOPPER
SCREW CONVEYOR
BUCKET ELEVATOR
BATCH STORAGE BIN
FURNACE FEEDER
GLASS-MELTING FURNACE

FIGURE 3. PROCESS FLOW DIAGRAM OF A TYPICAL BATCH PLANT(9)

all large manufacturers practice dust control, usually by means of cloth filters and baghouses.(4)

In the case of batch mixing and charging of clay pots or clay tanks used in manufacture of handmade glassware, the batch handling may be manual rather than automated.

Batch Composition

For the soda-lime-silica glasses, which represent the majority of pressed and blown tonnage, the basic batch ingredients are sand (silica), soda ash (sodium carbonate), limestone (calcium carbonate) and feldspar (a silicous mineral used as a source of alumina and alkali). Additionally, the batch will contain minor ingredients which promote fining, act as decolorizer or a colorant or impart other specific properties.

Borosilicate glass batches are also predominantly sand (silica) but boric oxide replaces much of the alkali content which is characteristic of soda lime-silica batches. The calcium plus magnesium oxide content is very low. A few percent of alumina and zero to a few percent of barium oxide are included. A higher melting temperature is required for borosilicate glasses than for soda-lime and volatility from the melt for borosilicate glasses is much higher.

In lead-alkali silicate glass batches, the lead oxide essentially replaces the lime of soda-lime glass; for the higher than soda-lime, but less than for borosilicate glasses.

The batch composition of common commercial opal glasses is basically similar to soda-lime glass but with modifications and additions. The alumina content is higher, lime lower and opacifiers are added such as fluorides or phosphates plus other minor ingredients.

Cullet (scrap glass) collected from the plant or sometimes purchased is added in varying amounts, usually between 10 and 50 percent, to the batch.(4) The quantity added depends primarily on its availability. In some processes, large amounts of cullet are produced (e.g., manufacture of lamps).

Melting and Fining

The melting, fining, and conditioning of the molten glass is done in three separate ways according to the amount of glass required. Continuous furnaces are standard for the machine-pressed and blown, tubing, television tube, and incandescent lamp glass subcategories. Clay pots and day tanks are used in the manufacture of hand-made ware. Continuous furnaces range in holding capacity from 1 to 500 tons, and outputs may be as high as 300 tons/day.(14) In general, more than 80 percent of the glass is melted in continuous regenerative furnaces which use preheated combustion air. Additionally, there are a number of fossil-fuel fired furnaces where the combustion air is not preheated, and some all-electric melters.

All furnaces which preheat the combustion air burn fossil fuels and some utilize additional energy input from electric "boosting". The furnaces in which the combustion air is preheated are generally classified as end-port or side-port regenerative. In the pressed and blown segment of the glass industry, practically every type of furnace is used. These are:

- Side-port regenerative
- End-port regenerative
- Unit melters
- All-Electric
- Electrically boosted
- Recuperative
- Day tanks/pot melters.

The type of furnace installed in each plant is dictated by such factors as local fuel cost and availability (fossil fuel versus electric), market size, plant floor space, or product volume desired.

Side-Port Regenerative. These furnaces utilize a design similar to that shown in Figure 4 which illustrates common features. Regenerators (refractory brick checkerworks) are attached to the furnace ports and used to preheat the incoming air, which is mixed with natural gas or oil as it enters the melting chamber. The regenerators are about two stories high and positioned on both sides of the furnace. The number of ports on a side varies from 3 to 7, depending upon furnace size. Batch enters the furnace where it is melted, fined (entrapped bubbles removed), and homogenized as it moves to the refractory-lined throat, where it passes into a conditioning chamber, popularly called the refiner.

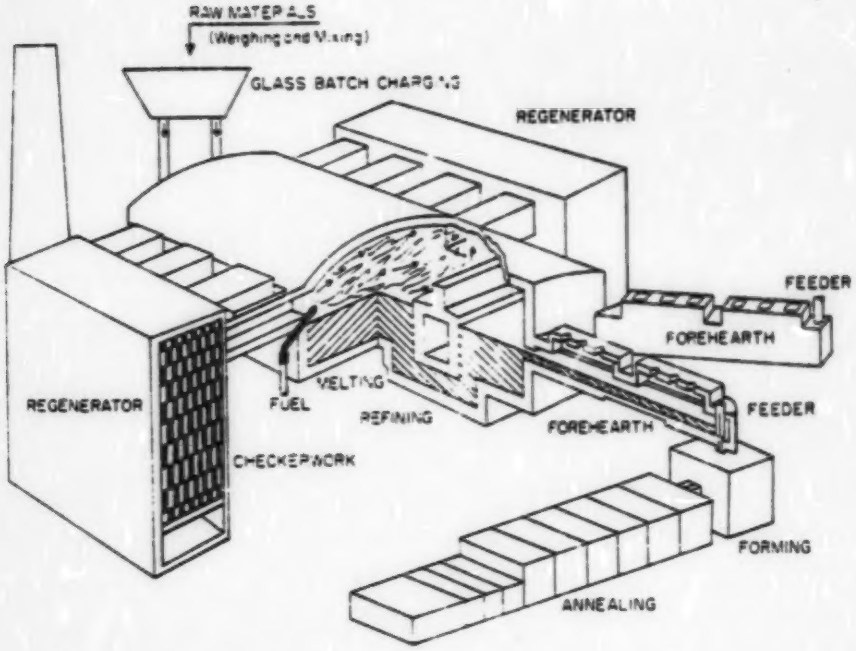
RAW MATERIALS
(Weighing and Mixing)
GLASS BATCH CHARGING
REGENERATOR
FEEDER
FOREHEARTH
REGENERATOR
FUEL
MELTING
REFINING
FOREHEARTH
FEEDER
CHECKERWORK
FORMING
ANNEALING

FIGURE 4. ILLUSTRATIVE SKETCH OF A CONTINUOUS TANK-TYPE OF SIDE-PORT REGENERATIVE-MELTING FURNACE(3)

End-Port Regenerative. The end-port furnace is also common furnace design. It has only two ports, located at the feed-end of the furnace. A flame is formed as the fossil-fuel/air mixture leaves one port and the combustion products travel in a horseshoe path over the molten glass until they exit through the second port. End-ports furnaces are usually smaller in size than sideport furnaces. However, considerable overlap in size does occur. While an exact estimate is not available, the combination of side-port and end-port regenerative furnaces account for the production of 75 percent or more of the glass melted by this industry.

Unit Melters. The unit melter is a non-regenerative, fossil-fuel fired melter. They are normally long and narrow and have a relatively low output (less than 100 tons per day). Their length to width ratio varies from 5:1 to 4:1 and they normally have 40 percent more surface area per ton of glass than a regenerative furnace.

All-Electric Melters. In all-electric melters, the glass is heated by its own self-resistance as an electric current passes through it. All-electric melters currently melt less than 10 percent of the glass in the United States. Because the energy is supplied internally to the glass, a higher percentage of the electrical energy can be converted into usable heat to melt the glass than with fossil-fuel fired melters. The melter is virtually free from any pollutants. Experience with larger melting furnaces (> 150 ton/day) does not exist.

Electrically Boosted Regenerative Melters. Many fossil-fuel fired furnaces are electrically boosted in order to obtain increased production or to reduce particulate emissions. Usually, 5 to 10 percent of the total energy input to the melter is supplied via electric boosting, although amounts up to 40 percent may be added when emission control is of primary concern. Since boosting can be added while the melter is operating and used only when needed, it is the most popular way of increasing the output of an existing furnace.

Day Tanks/Pot Furnaces. Pots and clay tanks are employed for the variable composition and small quantities of glass required in plants manufacturing handmade glass. The multi-pot furnace is the primary method of melting in these plants. Eight or more pots may be grouped in a circular arrangement as part of one furnace. Temperatures as high as 1600 C may be achieved. Pot capacities range from 9 kg to 1800 kg. A day tank is a single furnace and is somewhat larger than a pot, generally having a capacity of 900 to 3600 kg. Both pots and day tanks are batch fed at the end of the working day and allowed to melt overnight.

Forming

Several methods are used to form glass products in the pressed and blown industry. They include blowing, pressing, drawing, and casting.

Blowing. The individual section (I.S.) forming machine is used for making certain types of table and kitchenware. The molten glass is cut into gobs by a set of shear blades as the glass leaves the forehearth of the melting tank. Chutes direct the gobs into blank molds. The shear blade and chutes are lubricated and cooled with a spray of emulsified oil or a silicone-based solution. The molten glass gob is settled with compressed air, and preformed with a counter blow of compressed air. The preformed gob (parison) is then inverted and transferred into a blow mold where the glass product is finished by final blowing.

Incandescent lamp glass envelopes are formed using a ribbon machine. The ribbon machine employs modified blowing techniques to form the envelopes. The molten glass is discharged from the melting tank in a continuous stream and passes between two water cooled rollers. One roller is smooth while the other has a circular depression. The ribbon produced by the rollers is then directed horizontally onto a plate belt which runs at the same speed as the forming rollers. Each plate on the plate belt has an opening and the pill-shaped glass portion of the ribbon sags through the openings from the action of gravity. The glass ribbon is met by a continuous belt of blow heads that aid the sag of the glass by properly timed compressed air impulses premolding the glass. After the glass has been premolded, it is enclosed by blow molds which are brought up under the premolded glass on a continuous belt. The blow molds rotate about their own axis to produce a seamless smooth surfaces. Both the blow heads and molds are lubricated with a spray of emulsified oil. The formed envelopes (bulbs) are separated from the ribbon by scribing the neck of the bulb and tapping the bulb against a metal bar. Residual glass is collected as cullet. Figure 5 illustrates the ribbon forming machine.

Hand-blown glassware is made using a blowpipe. Molten glass is gathered on the end of the blowpipe and, using lung power or compressed air, is blown into its final shape. After the main section is formed, additional parts such as handles and stems can be added by gathering a piece of molten glass, joining it to the molded piece and then forming the joined pieces with special glassworking tools.

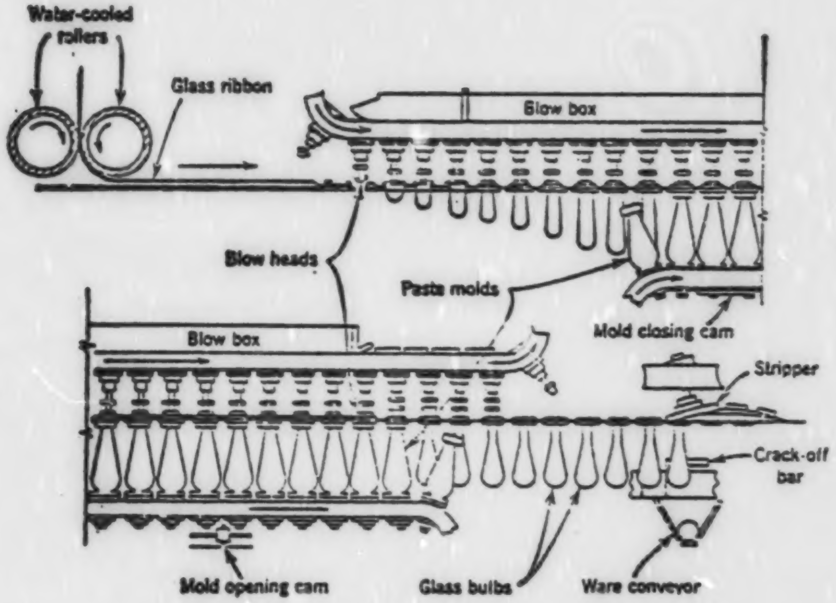
Water-cooled rollers
Glass ribbon
Blow box
Blow heads
Paste molds
Mold closing cam
Blow box
Stripper
Crack-off bar
Mold opening cam
Glass bulbs
Ware conveyor

FIGURE 5. THE CORNING RIBBON MACHINE(2)

Pressing. Over a fifth of the glassware is manufactured using presses. A press mold consists of three sections: the mold bottom, the plunger, and an enclosing ring that seals the mold between the mold bottom and the plunger. Pressing is done manually in the handmade subcategory or by machine in the remainder of the industry.

In manual pressing of glassware, molten glass is collected on a steel rod and allowed to drop into the mold bottom. When the proper amount of glass is in the mold, the glass remaining on the rod is separated from that in the mold by cutting with a pair of shears. The plunger is then forced into the mold with sufficient pressure to fill the mold cavities. The glass is allowed to set up before the plunger is withdrawn and the pressed glass removed from the mold.

Machine pressing is done on a circular steel table. The glass is fed to the presses in gobs from a refractory bowl at the end of the forehearth of the melting tank. The molten glass is cut into gobs by oil-lubricated shear cutters beneath the orifice of the refractory bowl. The motions of the shear blades and the press table are synchronized such that the gobs fall into molds on the press table. After the gob is received in the mold, it moves to the next station on the press table, where it is pressed by a plunger. In the remaining stations, the pressed glass is allowed to cool before it is removed from the press and conveyed to the annealing lehr. The mold bottoms are usually cooled by air jets and the plunger sections are cooled with internally circulated water. The mold temperature is critical and dependent upon the type of glass being made. If the mold is too hot, the molded piece will stick to the mold and if it is too cold, the piece may have an uneven surface. In some cases, the mold is sprayed with water and lubricants prior to receiving the glass. The steam formed when the molten glass is introduced helps prevent sticking. Machine pressed glass products include tableware, lenses, reflectors, and television picture tube faceplates.

Drawing. Glass tubing may be formed using one of three different processes. In the Danner process, a regulated amount of glass falls upon the surface of a rotating mandrel which is inclined to the horizontal. Air is blown continuously blown through the center of the mandrel to maintain the bore and the diameter of the tubing as it is drawn away from the mandrel. The tubing is pulled away from the mandrel on rollers by the gripping action of an endless chain. Tubing dimensions are controlled by the drawing speed and the quantity of air blown through the center of the mandrel. The tubing is scribed by a cutting stone that is accelerated to the drawing speed and pressed vertically against the tubing and which is then cut by bending against a spring controlled roller.

In the Vello process, the molten glass passes downward through the annular space between a vertical mandrel and a refractory or steel ring set in the bottom of a special forehearth section of the melting tank. The tubing is drawn away from the melting tank by a Vello machine and cut in a manner similar to that used for the Danner process.

The updraw process is used to make large diameter tubing and glass pipe. In the Updraw process, the tubing is drawn upward from a refractory cone. Air is blown up through the cone to control dimensions and cool the tubing. The tubing is cut into lengths at the top of the draw.

Casting. Television picture tube envelope funnels are normally formed by centrifugal casting, although occasionally they are pressed. Molten glass is cut into gobs by oil-lubricated shear blades, and the glass gob dropped into the mold. The mold is spun rapidly so that the centrifugal force causes the glass to flow up the sides of the mold to form a wall of uniform thickness. Newer processes seal against a ring, much like pressed glass, while older methods entail cutting off the upper edge of the funnel.

Post-Forming and Finishing

This part of production can consist of many operations depending upon the particular product being manufactured. Thy include: surface treatments, annealing, decorating or engraving, cutting, sealing, polishing, etching, and coating. Prior to annealing and sometimes after, glassware may receive surface treatments to improve its chemical resistance or improve abrasion resistance. Many products are fire-polished, which involves passing newly formed ware through a line of oxygen-gas burners that are directed onto the ware to smooth out ridges or edges. After fire-polishing, the ware goes into a lehr for a normal annealing cycle.

After the glass is formed, annealing is usually required to relieve strains that might weaken the glass. The entire piece of glassware is brought to a uniform, elevate temperature (590 to 650 C) to permit the release of internal stresses and then it is cooled at a uniform rate to prevent new stresses from developing. Annealing is done in long continuous ovens called lehrs. Heat treating to allow a portion of the glass to crystallize may also be done in lehrs. After heat treatment, some ware may be decorated with enamel colors applied to annealed articles and then refired in annealing lehrs.

Television picture tube envelopes are manufactured in two pieces, referred to as the screen and funnel. Both pieces require the addition of components prior to annealing and several finishing steps follow annealing. After forming and prior to annealing, the seam (shearmark) on the screen is fire polished and mounting pins are installed using heat. The mounting pins are required for proper alignment when the electronic components are placed into the picture tube. The stem portion and an anode to be used as a high voltage source are added to the funnel prior to annealing by fusion into the funnel. Following annealing, screens and funnels are visually inspected for gross defects such as large stones, blisters, and entrapped gas bubbles. The screen dimensions and mounting pin locations are then gaged to check for exactness of assembly. The funnel portion is not gaged until all finishing steps are completed.

Screens and funnels are finished separately using different equipment. The first finishing step applied to the television screen section is abrasive polishing. Polishing is required to assure a flawless and parallel surface alignment so that an undistorted picture will be produced when the tube is assembled. The edge of both the screen and funnel must be perfectly smooth so that a seal will be formed when the two sections are glued together. The seal must be sufficiently tight to hold a vacuum. Abrasive polishing is accomplished in four steps using rough and smooth garnet, pumice, and rouge or cerium oxide. The abrasive compounds are in a slurry form and are applied to the screen surface by circular polishing wheels of varying texture. Between each polishing step the screen is rinsed with water. The slurry solutions are generally recycled through hydroclones or settling tanks and only fine material too small to be useful for grinding or polishing is wasted. Following abrasive polishing, the screen edge is ground, bevealed, and rinsed with water. This edge is then dipped in a hydroflouric acid solution to polish and remove surface irregularities. This step is commonly referred to as fortification. Following rinsing, to remove residual acid, and drying, the screen receives a final inspection. The front edge of the funnel is polished with a diamond wheel and fortified as previously described. The polishing surface is bathed in oil and, therefore, the funnel must be rinsed with water and dried before final gaging and inspection.

Incandescent lamp envelopes are generally frosted. After annealing, the envelope interior is sprayed successively with several frosting solutions. The specific formulation of these solutions is proprietary, but primary constituents include hydroflouric acid and other fluoride compounds, ammonia, water, and soda ash. Residual frosting solution is removed in several rinse stages.

The manufacture of hand pressed and blown glass also involves several finishing steps including: crack-off, washing, grinding and polishing, cutting, acid polishing, and acid etching. The extent to which these methods are employed varies substantially from plant to plant. Many plants use only a few of the finishing methods, of which washing, grinding, and polishing are the most prevalent.

Crack-off is required to remove excess glass that is left over from the forming of hand-blown glassware. Crack-off can be done manually or by machine. When a machine is used for stemware, for example, the stemware is inserted into the crack-off machine in an inverted position. The bowl of the stemware is scribed by a sharp edge, the scribed edge passes by several gas flames and excess glass is broken off. The scribed surface is then beveled on a circular grinding medium similar to sandpaper. Carborundum sheets are used in most cases. The grinding surface is sprayed with water for lubrication and to flush away glass and abrasive particles. Hydrofluoric acid polishing of the beveled edge may follow crack-off and is considered part of the crack-off operation in this study. This operation involves rinsing the glassware in dilute hydroflouric acid and city water, and in some cases, a final deionized water rinse.

Cutting as applied to handmade glassware manufacturing may be defined as the grinding of designs into the glassware or as the removal of excess glass left over from forming. Designs may be placed onto the glassware manually or by machine. In mechanical design cutting, the ware is placed on a cutting machine and is rotated in a circular motion. Designs are cut into the surface at the desired points using a cutting edge. In the other form of cutting a saw may be used to remove excess glass from some handmade products. Water is used in both machine design cutting and sawing to lubricate the cutting surface and to remove cutting residue.

Acid polishing may be employed to improve the appearance or to remove the rough edges from glassware. Automatic machines or manually dipped racks may be employed. In the manual operation, the glassware is placed in racks and treated with one or more hydrofluoric acid dips followed by rinsing. The complexity and number of steps is determined by the product.

Abrasive polishing is used to polish the glass surfaces and edges on some types of handmade glassware. The glassware is placed in a bath of abrasive slurry and brushed by circular mechanical brushes or polishing belts. After polishing, the ware is rinsed with water in a sink and dried.

Complicated designs may be etched onto handmade stemware with hydrofluoric acid. The design is first made on a metal template and is transferred from the template to a piece of tissue paper by placing a combination of beeswax and lampblack in the design and then pressing the tissue paper against the design. The tissue paper is placed on the stemware and then removed leaving the pattern in wax. All parts of the ware except for the pattern are then coated with wax. The wax-coated stemware is placed in racks and immersed in a tank of hydroflouric acid where the exposed surfaces are etched. Following a rinse to remove residual acid, the ware is placed in a hot water tank where the wax melts and floats to the surface for skimming and recycling. Several additional washes and rinses are required to clean the ware and to remove salt deposits from the etched surfaces. In some cases, a nitric acid bath may be used to dissolve these deposits. Deionized water may be used for the final rinse to prevent spotting.

SECTION IV

EMISSIONS

Emissions from pressed and blown plants are categorized according to three operations within the manufacturing process

- Particulate emissions from the raw-materials handling, preparation, and transfer.
- Gaseous and particulate emissions from the glass-melting furnace. These emissions are primarily SO_x, NO_x, submicron condensates, hydrocarbons, CO, fluorides, borates, and lead oxides.
- Gaseous and particulate emissions from a variety of forming and postforming operations. These result from annealing, decorating, surface treatment, and coating operations and can include particulates, hydrocarbons, NO_x, and SO_x.

This section describes the various emissions, their characteristics, their levels, total quantities, and environmental effects. The information is organized according to the three sources within the manufacturing process

- Raw-materials preparation and handling
- Glass melting
- Forming and finishing.

Raw-Materials Preparation and Handling

Typical points of particulate emissions during raw-materials preparation and handling are shown in Figure 6. These points include

- Unloading and conveying
- Crushing of cullet (scrap glass)

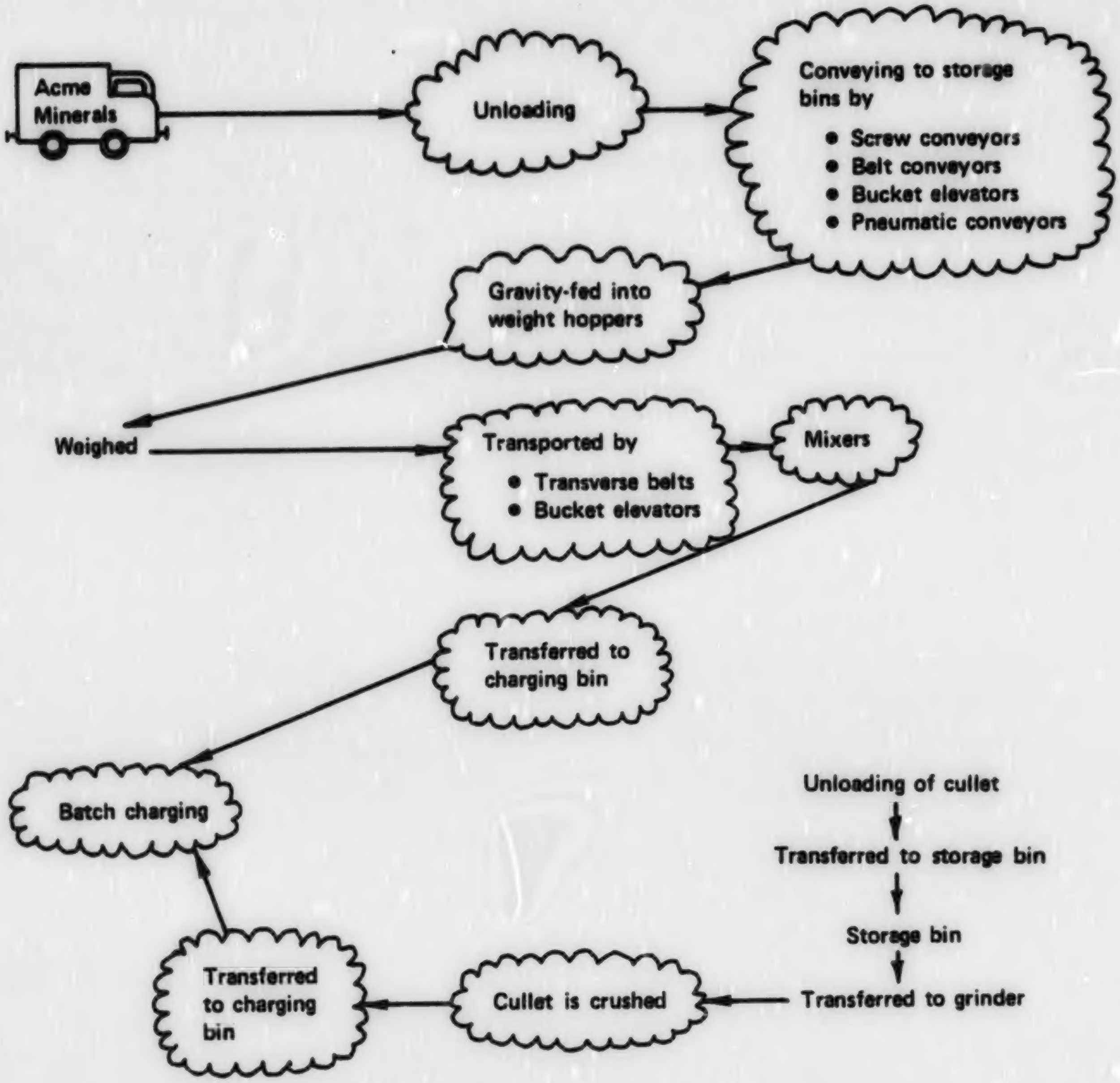
Acme Minerals
Unloading
Conveying to storage bins by
• Screw conveyors
• Belt conveyors
• Bucket elevators
• Pneumatic conveyors
Gravity-fed into weight hoppers
Weighed
Transported by
• Transverse belts
• Bucket elevators
Mixers
Transferred to charging bin
Batch charging
Unloading of cullet
Transferred to storage bin
Storage bin
Transferred to grinder
Cullet is crushed
Transferred to charging bin

FIGURE 6. TYPICAL POINTS OF PARTICULATE EMISSION FROM RAW-MATERIALS HANDLING

- Filling and emptying of storage bins
- Weighing and mixing of batches
- Feeding of batch to glass furnace (batch charging).

However, those uncontrolled particulates which remain in the manufacturing plant may constitute an OSHA health and safety problem distinct from plant emissions.

For the purposes of this study, fugitive-dust emission has been defined as particulate emissions that result from industrial-related operations, and which escape to the atmosphere through windows, doors, vents, etc., but not through a primary exhaust system, such as a stack flue, or control system. This definition is derived in part from a paper presented by Lillis and Young of the U. S. Environmental Protection Agency.(7) Information obtained from ambient sampling up-wind and down-wind of the manufacturing facility is the preferred source of data. If actual data from high-volume samples are not available, engineering estimates based on the particle size of raw material which can contribute to dust emissions are desired. For the purposes of this study, the particle size range of the raw materials which will be considered as contributing to fugitive dust emissions is 100 microns or less in diameter. This definition of dust is not as broad as the technical definition given by Stern,(8) but this particle-size distribution seems reasonable for glass-manufacturing processes. The settling velocity of a 100-micron-diameter sphere, with a specific gravity of 2.0 g/cc, is approximately 50 cm/sec in still air at 25 C and 1 atm. Such a settling rate is sufficiently slow that the emission of dust from a tall source, such as the raw materials storage bins, would probably contribute to the total air emissions.

Dust is usually emitted during unloading and conveying operations. To minimize dust emissions, these operations are generally enclosed and the vents on storage bins and mixers exhausted through fabric filters. Batch wetting, the addition of water to the batch during the mixing operation, is another practice commonly used to minimize particulate emissions. As a result, limited data on particulate emissions from primary exhaust systems are available, and no data are available on fugitive dust. Particulate-emission data from point-source measurements have been reported in NEDS(9) (National Emission Data System) and are given in Appendix B. Although these particulate emission data were not listed by specific ingredients, the data enable the calculation of overall average emission factors for raw-materials handling and preparation. This overall emission rate is determined to be 1910 mg/kg ±100 percent. Total annual particulate emissions for raw-materials handling and manufacturing are 6.44 mg ±100 percent, based on 3.37 Tg of raw materials being processed to produce 2.97 Tg of glass, and is equivalent to 0.0004 percent of the national particulate emissions from stationary sources. Table 5 shows a breakdown of raw-materials handling for the various points of emission. This listing has been determined primarily by NEDS data(9) and confirmed by observations made during plant visits. The ingredients contained in these particulate emissions reflect the raw material used in the manufacturing process (soda ash, limestone, feldspar, quartz, PbO, borates, and fluorides), since no chemical reaction have taken place. Quantitative data on the amount of each ingredient emitted are not available.

Pressed and blown glass manufacturers minimize the dusting problem by limiting the amounts of fine particles (<100 micron) in the batch material. Manufacturers generally specify particulate sizes ranging from 820 to 44 micron (-20, +325). Table 6 shows the specification limits for several of the raw materials used in the manufacture of pressed and blown glassware. Since most of the materials have specified particle size limits greater than 100 microns (150 mesh), the amount of material emitted from the plant site due to inertial forces is minimal. Note also that quartz particles in the mix are generally larger than 100 microns in diameter and, as such, would not be expected to be emitted as respirable quartz either through the stacks or as fugitive dust. Based on information available from raw-materials suppliers, a reasonable assumption is that <1 percent of the materials used have a particle size less than 100 microns in diameter (150 mesh). Assuming at least 90 percent of dust emissions are captured in fabric filters (fabric-filter efficiency is >98 percent), then approximately 4 mg of fugitive dust would be emitted annually (based on 3.37 Tg of raw materials produced annually). These data appear consistent with both observations from plant visits and information obtained from pressed and blown glass manufacturers.

TABLE 5. PARTICULATE EMISSIONS DURING RAW-MATERIAL PREPARATION AND HANDLING FOR PRESSED-AND-BLOWN GLASS

Process Step	Emission Factor mg/kg	Total Annual Emissions[(a)] Mg
Handling (unloading, conveying	1500 ± 100%	5.06
Glass crushing	Negligible[(b)]	-
Storage bins	100 ± 100%	0.34
Mixing and weighing	310 ± 100%	1.04
Batch charging	Negligible[(b)]	-
Total	1910 ± 100%	6.44

(a) Based on 3.37 Tg of raw materials processed to melt 2.97 of glass

(b) <0.1

TABLE 6. SPECIFICATION LIMITS FOR SEVERAL RAW MATERIALS USED IN PRESSED-AND-BLOWN GLASS MANUFACTURE(14)

		Material Specifications Range			
		Minimum		Maximum	
Mineral	Chemical Formula	Amount(%)	Mesh[a]	Amount(%)	Mesh[a]
Arsenic Trioxide	AS_2O_3	9	+20	14	-325
Cerium Oxide	CeO_2	-	-	100	-60
Dolomite	$(Ca,Mg)CO_3$	0.5	+16	50	-100
Feldspar	-	2	+40	10	-200
Limestone	$CaCO_3$	0.2	+20	0.5	-300
Sand	SiO_2	3	+30	6.6	-100
Soda Ash	Na_2CO_3	0	+20	4.2	-120
Sodium Nitrate	$NaNO_3$	1	+6	1.5	-100

[a] See Table 16 for micron equivalents.

Glass Melting

In the United States, pressed and blown glass is predominantly melted in fossil-fuel-fired furnaces. Emissions from these furnaces are by far the largest source of pollutant from a glass plant. The type of pollutant emitted depends on the glass composition and the furnace operating conditions. These emissions will include NO_x, SO_x, particulates, CO, hydrocarbons, selenium, fluorides, borates, and lead compounds.

The overall emission rates and total emissions for furnaces melting soda lime, borosilicate, opal, and lead glasses are given in Table 7. The emission factors are based upon data reported in NEDS(9) and derived from various other sources. Data referred to as source measurements, as reported in NEDS, have been obtained by actual point source test measurements. The emission rates are highly dependent upon the operating conditions of the glass-melting furnace. For instance, emissions are reported to range from trace amounts* to a high of 10 g/kg of glass melted for NO_x, 5.44 g/kg for SO_x, and from 0.49 g/kg to 12.57 g/kg for particulates. Each type of emission is discussed in greater detail for the various types of glasses. As has been shown previously, (page 15) soda-lime, borosilicate, opal, and lead glass are estimated to comprise approximately 77, 11, 7, and 5 percent, respectively, of the glass produced in the United States.

Nitrogen Oxides

In a fossil-fuel-fired furnace, nitrogen oxides (e.g. NO and NO_2) are formed by a combination of atmospheric nitrogen and oxygen at the elevated temperatures (> 1500 C) required for making glass. Because of the high temperature, NO would be expected to be the primary oxide of nitrogen formed. For purposes of this analysis, nitrogen oxides are designated as NO_x. In this study, NO_x is compared against the NO_2 air quality standard. The assumption that the NO_2 emission factor is equal to the NO_x emission factor is believed valid because once the plume has been diluted sufficiently with air (dispersion calculations show that the plume is diluted approximately 1000 to 1 at the point

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* Trace < 0.001 g/kg of glass melted

TABLE 7. EMISSIONS FROM PRESSED AND BLOWN GLASS MELTING FURNACE OPERATIONS

	Emission Factor, g/kg					Total Annual Emissions[(a)], Gg					Percent of National Emissions from all Stationary Sources				
Species	Soda/Lime	Borosilicate	Opal	Lead	Total	Soda/Lime	Borosilicate	Opal	Lead	Total	Soda/Lime	Borosilicate	Opal	Lead	Total
NO_x	4.25 ± 43%	—	—	—	4.25 ± 43%	10.0	—	—	—	12.6[(b)]	0.086	—	—	—	0.109[(d)]
SO_x	2.68 ± 50%	2.99 ± 100%	—	—	2.80 ± 62%	6.3	1.1	—	—	8.3[(b)]	0.010	0.002	—	—	0.013
Particulates	5.22 ± 43%	25 ± 100%	5 ± 100%	15 ± 100%	8.70 ± 60%	12.3	9.0	1.1	0.4	25.8	0.009	0.007	0.001	—	0.020
CO	0.10 ± 100%	—	—	—	0.10 ± 100%	0.2	—	—	—	0.3[(b)]	0.002	—	—	—	0.002
HC	0.15 ± 53%	—	—	—	0.15 ± 53%	0.3	—	—	—	0.4	0.001	—	—	—	0.001
Fluorides	0	10 ± 100%	10 ± 100%	10 ± 100%	10 ± 100%	0	0.7[(c)]	2.2	0.1[(c)]	3.0	—	—	—	—	—
Selenium	—	0	0	—	0.002	—	0	0	—	9	—	—	—	—	—

(a) Based on 2360, 360, 220, and 30 Gg of glass produced annually for soda/lime, borosilicate, opal, and lead glass.

(b) Assumes equivalent emission factor for other glass types.

(c) Not found in all glass melted.

(d) Standard for NO_2

where it touches the ground), the photochemical conversion of NO to NO_2 is quite rapid. This report does not attempt to determine the relative proportions of each gas.

Nitrogen oxides represent the second largest mass fraction (∿21%) of emissions from the glass-melting furnace. As seen in Figure 7, the formation of NO_x in a glass-melting furnace is extremely temperature sensitive. In one case, NO_x concentration has been observed to increase some six times (from 100 ppm to ∿600 ppm) as the furnace temperature (measured at the bridgewall) increased from 1460 to 1550 C and the production rate of a soda lime glass doubled(10). The rate of NO_x formation depends upon factors such as peak flame temperature, percent excess oxygen, and post-time/temperature history of the flame. Consequently, considerable variation in the rate of NO_x emissions can and does occur.

Soda/Lime Glass. Source measurements reported in NEDS(9) and taken from the open literature give an average emission rate of 4.25 g of NO_x per kg of soda lime glass produced. This average is based on 14 measurements (see Appendix B) and is calculated to be accurate to within ±43 percent at a 95 percent confidence level. Individual values range from 0.41 to 10.0 g/kg. The average NO_x emission amounts to approximately 10.0 Gg og NO_x emitted annually from furnaces melting soda lime glass, which is equivalent to approximately 0.086 percent of 1972 National NO_2 emissions from all stationary sources(11) (Appendix D).

Other Glasses. No point source measurements were reported in NEDS(9) nor available from the open literature for NO_x emissions from furnaces melting borosilicate, opal or lead glasses. The emissions from furnaces melting borosilicate glass are expected to be higher than that reported for soda lime because of the higher melting temperatures required. Furnaces melting opal and lead glasses would be expected to be equal to or lower than those found for soda lime, since processing temperatures are similar or lower.

The maximum NO_x emissions expected for borosilicate glass is estimated to be three times that observed for soda lime glass or about 13 g/kg. This emission rate will produce total annual emissions of 4Gg or 0.035 percent of the 1972 National NO_2 emissions from all stationary sources(11).

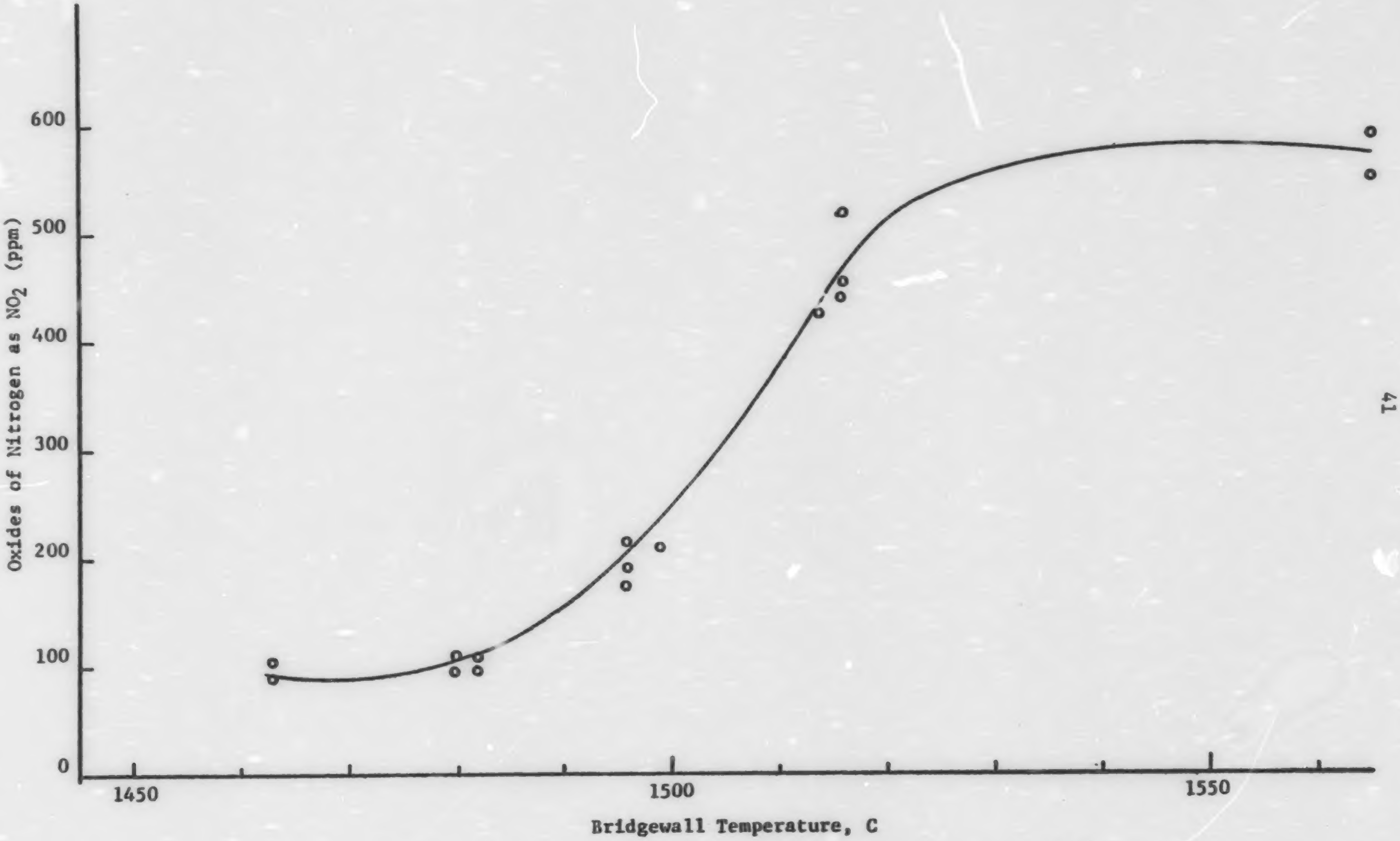

FIGURE 7. NO_x EMISSIONS FROM FLINT GLASS-CONTAINER FURNACE(18)

Sulfur Oxides

Sulfur oxide emissions can occur through both the decomposition of sulfates (e.g., Na_2SO_4) added in the glass batch and from the oxidation of sulfur in the fossil fuel. When oil is used as the fossil fuel, a large majority (> 80 percent) of sulfur oxide emissions are derived from sulfur in the oil(13). Sulfur oxides from the batch generally combine with alkali volatiles and exit as a particulate, while sulfur in the fossil fuel exits predominately at SO_x. While some glasses contain no sulfur (e.g. borosilicates), it is present in all soda lime glasses. Soda lime glass generally contains about 0.15 weight percent sulfate (added usually as salt cake, gypsum, or blast-furnace slag) which is added for melting and finishing purposes and is a necessary ingredient for making container glass. The range of values for sulfate ($SO_4^=$) in glass as reported in 1973 varies from 0.03 to 0.32 percent, with 82 percent of some 106 analyzed glasses falling between 0.10 and 0.20 percent(13). The amount of mineral sulfate added in the batch will, of course, be higher and usually falls within the 0.5 to 1.0 percent range. Sulfur oxide emissions from the batch materials do occur(10,12) and these depend primarily upon the quantity of glass melted.

Sulfur oxide emissions will be greatly influenced by any switch from natural gas (the primary fossil fuel), which is essentially sulfur-free to fuel oils or powdered coal containing sulfur. Such a trend does exist primarily because of the reduced availability of natural gas in most sections of the country. Sulfur in fossil fuels readily oxidizes in the glass-melting furnace and appears as SO_x in the exhaust gases. For instance, a fuel oil containing one weight percent sulfur emits approximately 600 ppm (calculated as SO_2) in the flue gas(13).

An approximate materials balance, which illustrates the dependence of SO_x emissions on the fossil fuel and batch materials as follows for a furnace producing approximately 136 Mg/day (150 tons/day) of a soda lime glass used for light bulbs(14):

	Natural Gas	No. 5 Fuel Oil
Sulfur Input		
Batch	2.5 kg/hr (5.6 lb/hr)	2.9 kg/hr (6.4 lb/hr)
Fuel	0.0 kg/hr	5.3 kg/hr (11.6 lb/hr)
Total	2.5 kg hr (5.6 lb/hr)	8.2 kg/hr (18.0 lb/hr)
Sulfur Output		
Glass	2.3 kg/hr (5.0 lb/hr)	2.6 kg/hr (5.7 lb/hr)
Particulates	0.3 kg/hr (0.6 lb/hr)	0.3 kg/hr (0.7 lb/hr)
SO_x	<0.1 kg/hr (<0.1 lb/hr)	5.0 kg/hr (11.0 lb/hr)
Total	2.6 kg/hr (5.6 lb/hr)	7.9 kg/hr (17.4 lb/hr)

This example illustrates that the sulfur oxides predominately result from the fuel used.

Source measurements reported in NEDS or in the literature are essentially for natural gas-fired furnaces. Hence, the emissions are not fully representative of an industry which is gradually switching to fuels containing sulfur. However, such future emissions will essentially correspond directly to the sulfur found in the fuel oil or powdered coal.

Soda/Lime Glass. Only three source measurements are available for SO_x emissions from furnaces producing soda lime glass. These sources gave an average SO_x emission rate of 2.68 g/kg of glass melted. A reasonable way to assign an accuracy to these values in nonexistant. Individual SO_x emissions from furnaces melting soda lime glass in the pressed and blown industry is 6.3 Gg, which is equivalent to 0.086 percent of 1972 National SO_x emissions from all stationary sources.

Borosilicate Glass. Two point source measurements were reported$^{(9)}$ for SO_x emissions from furnaces producing borosilicate glass. Since sulfates were not used as batch materials in borosilicates, these emissions must have been taken from oil fired furnaces. The individual rates were 0.54 and 5.44 g/kg for an average of 2.99. If all borosilicate glass melted had this emission rate, total annual SO_x emissions would be 1.1 Gg.

Other Glasses. Sulfates are also not used as batch materials in opal and lead glasses. Emissions of SO_x from furnaces melting these glasses would only occur from sulfur in the fossil fuel. No information was available for furnaces using fuel oil to produce these glasses. Some aluminosilicate and opthalmic glasses used sulfate-containing raw materials; however, no information was available.

Fluorides

Fluoride emissions can occur from furnaces melting opal, corosilicate, and lead glasses. These emissions come from batch materials such as fluorspar (CaF_2), K_2SiF_6, $NaSiF_6$, Lepidolite, and Cryolite (Na_3AlF_6). Fluorine acts as as a flux and the fluoride can remain as a separate phase when the glass cools, imparting a milky white color to the finished product. (e.g., opal glass). During melting, a portion of the fluorides in the batch volatizes and escape as gaseous compounds. Some of these compounds are retained in the glass and some can also be emitted as particulates. The gaseous compounds include HF, BF_4, SiF_4.

Total fluoride emissions, either as a gas or particulate, were calculated on a worst-case basis from data reported in the literature(15,16,17). Assuming the worst-case emission rate as 10 g/kg (as F^-) of glass melted and a total annual production of glass containing fluorides as 0.30 Tg, total annual emissions would be 3.0 Gg of F^-.

Carbon Monoxide

Carbon monoxide can be emitted through incomplete combustion of the fossil fuel through the use of a luminous flame, or by reaction of a powdered coal added to the glass batch to reduce sulfate compounds. Only three emissions on soda lime glass were available, and they gave an emission rate of 1.10 g/kg, which is considered to be a worst-case situation. This emission rate is believed accurate to within ±100 percent at a 95 percent confidence level and represents an annual emission of 0.29 Gg of CO, or 0.002 percent of 1972 National CO emissions from all stationary sources. CO emissions would be expected to be independent of glass type.

Hydrocarbons

Hydrocarbon emissions form in glass-melting furnaces primarily through the incomplete combustion of a fossil fuel. Hydrocarbon source test measurements are limited. An estimated average emission rate for soda lime glass is 0.15 g/kg, based on seven measurements calculated to be accurate to within ±53 percent. Such an emission rate represents an annual emission of 0.44 Gg of hydrocarbons or 0.0012 percent of 1972 National emissions for hydrocarbons from stationary sources. Hydrocarbon emissions would be expected to be independent of glass type.

Particulates

Particulates from glass-melting furnaces can originate both from physical entrainment of batch materials being charged to the melting furnace and from condensation of compounds, such as sodium sulfate (which forms from sulfur oxides and volatized sodium). Particulates exiting with exhaust gases are essentially all (> 95 percent) condensates, as indicated by the solubility of the collected residues in water. Studies do show that batch materials are carried out of the furnace by the combustion products; however, such materials usually do not show up in the stack-gas samplings; therefore, these coarser batch materials are assumed to be retained in the furnace-flue system(18,19).

Considerable opinion exists as to the exact mechanisms by which condensate particles are formed. For soda-lime glasses, analyses have shown the particulates to consist predominately (> 75 percent) of submicron sodium sulfate (5,10,18). The particulates from borosilicate glasses are made up of boric oxide, alkali borates (e.g., $Na_2B_4O_7$ and NaCl). With lead glass, the particulates consist of lead oxide, sulfate and anhydrite. When the furnace is fired with oil, the particulates change color from yellow to white, because $PbSO_4$ is emitted. The particulates can also contain NaF, Na_2SO_4, and Sb_2O_3. The particulates from opal glass contain B_2O_3, NaF, and Na_2SiF_6.

Uncontrolled particulate emissions are least for soda lime glasses, intermediate for lead glasses, and highest for borosilicate glasses. For one manufacturer(14), uncontrolled particulate emissions for glass melting furnaces producing 75 to 100 tons/day will normally be approximately 2.3 kg/hr for soda-lime, 9.5 kg/hr for lead, and 15 kg/hr for borosilicate glass. Another manufacturer(33) reported uncontrolled emissions for lead glasses to be about 15 g/kg and about 25 g/kg for borosilicate glasses.

The formation of particulates depend upon batch composition (type of glass), temperatures in the melting furnace, production rate, surface area of molten glass, and cullet ratio. Of these factors, glass composition, production rate, and temperature of the molten glass are the more important factors affecting particulate emissions. Since these variables are interrelated, determination of the relative influence of each variable is difficult although, for a given composition, temperature appears to be the most significant variable. Data from one furnace melting a soda lime glass shows that at zero production rate (tank soaking), the particulate emissions are approximately 20 percent of that measured at its normal furnace capacity(10). While temperature is maintained at a constant value (1450 C), emissions range from 1.814 kg/hr (4 lb/hr) at zero pull to 7.711 kg/hr (17 lb/hr) at normal pull of 211 Mg/day. Other data(10) collected on soda lime glass during this study, indicate that particulate emissions follow an Arrhenius curve when plotted against the reciprocal of temperature; that is, a linear relationship with the logarithm of the emission rate. This relationship is shown in Figure 8. Similar results are found for a borosilicate glass(14). Figure 9 shows the emission rate as a function of pull rate for soda lime and borosilicate glasses. Note that particulate emissions occur even at a zero pull rate, so long as the temperature of the furnace is maintained.

Particulate emissions taken from glass melting furnaces have been found to be generally submicron in size. In one study(20), particulate emissions from furnaces melting soda lime glasses averaged 0.13 micron.

Soda Lime Glass. Source measurements for particulate emissions from soda lime glass-melting furnaces give an average emission rate of 5.22 g/kg. This emission rate varies from 0.49 g/kg to 12.57 g/kg. Source measurements are from 19 points and are calculated to be accurate within ±43 percent at a 95 percent confidence level. These emissions represent an estimated total annual particulate emission of 12.3 Gg or 0.009 percent of the 1972 National particulate emissions from all stationary sources(11).

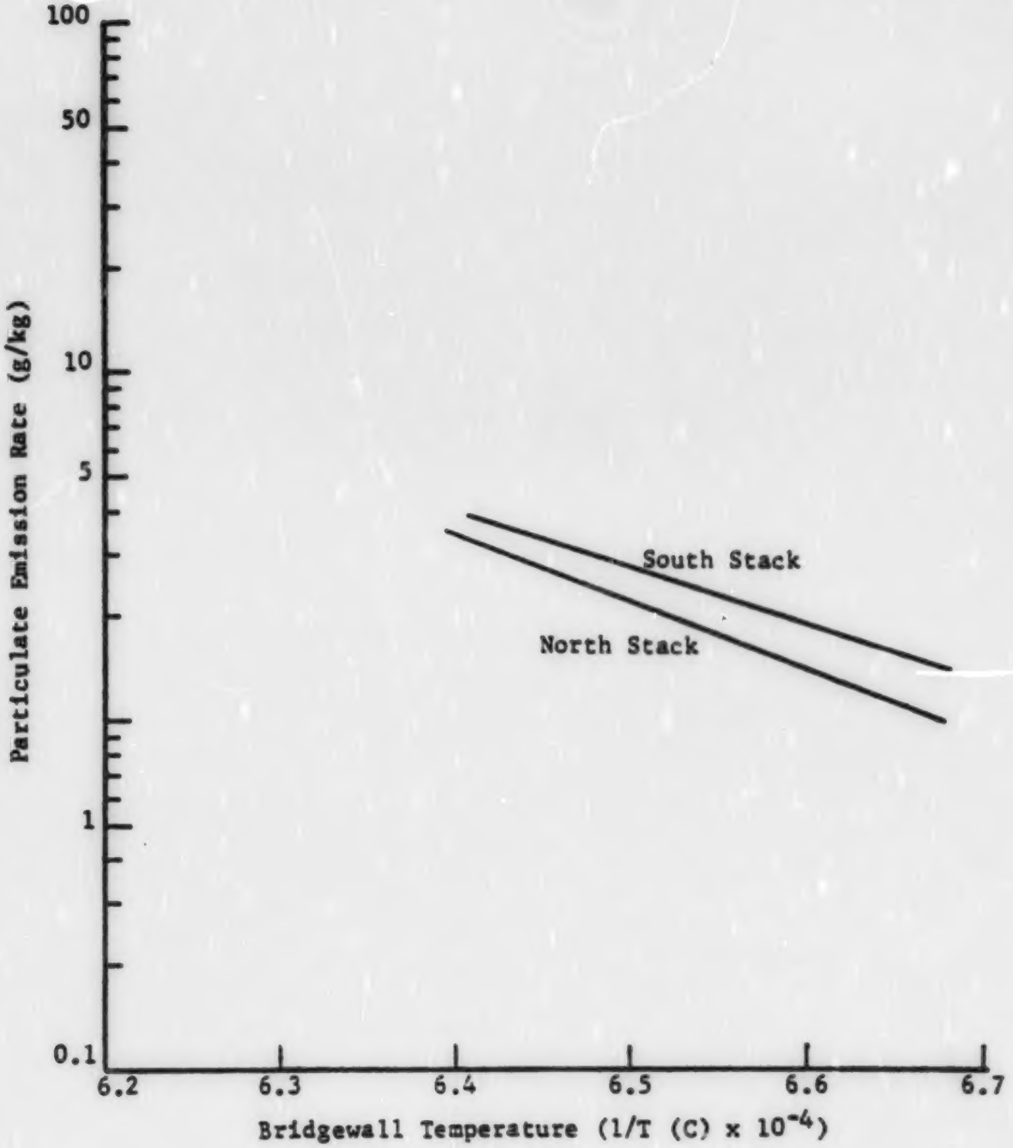

FIGURE 8. PARTICULATE EMISSIONS SHOWN ARE LINEAR WITH THE RECIPROCAL OF BRIDGEWALL TEMPERATURE

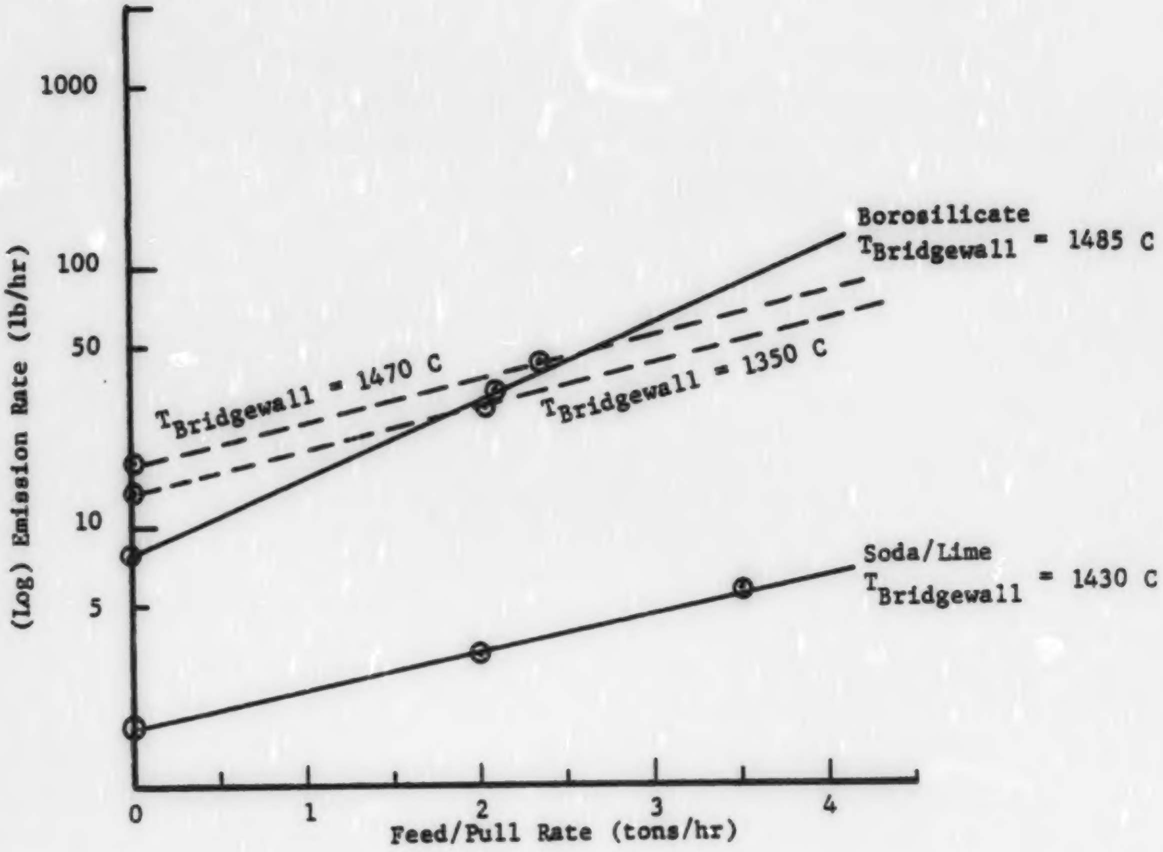

FIGURE 9. PARTICULATE EMISSIONS FOR GLASSES AS A FUNCTION OF PULL RATE

Borosilicate Glass. Source measurements for particulate emissions from borosilicate glass-melting furnaces were not available. Using a worst-case, uncontrolled emission rate of 25 g/kg, the total annual particulate emission was estimated to be 9.0 Gg or 0.007 percent of the 1972 National particulate emissions from all stationary sources(11).

Opal Glass. Source measurements for particulate emissions from opal glass-melting furnaces were not available. Using a worst-case, uncontrolled emission rate of 5 g/kg, the total annual particulate emission would be 1.1 Gg, or 0.001 percent of the 1972 National particulate emissions from all stationary sources(11).

Lead Glass. Only one source measurement was available for particulates from furnaces melting lead glass (4.52 g/kg). Using a worst-case uncontrolled emission rate of 15 g/kg, the total annual particulate emissions would be 0.30 Gg, or 0.0002 percent of the 1972 National particulate emissions from all stationary sources(11).

Selenium

Selenium is used by glass manufacturers as a decolorizer to neutralize the tint from transition metal oxide contaminants such as iron, and is usually used in amounts of less than two weight percent(5,6,18). Source measurements on selenium emissions are unavailable. Selenium volatizes at rather low temperatures (315 C for SeO, 685 C for Se)(5,18); therefore, it can be expected to be present in the waste gases. If the temperature of the waste gases is below 200 C, selenium condensates are likely to be found. Approximately 0.359 Gg of selenium are consumed annually in the United States(23), of which an estimated 5 percent or 0.018 Gg is used by the pressed and blown glass industry. Under the worst case, approximately half of the selenium will be emitted, representing an emission rate for selenium of 0.002 g/kg. Using these estimates, total annual emissions will be 0.002 Gg.

Other Emissions

Other minor emissions can include antimoney and arsenic, which are sometimes added as fining and decolorizing agents. The use of both of these materials has been steadily declining in recent years. Similarly, chlorine can be emitted because of its association with soda ash produced by the Solvay process. In recent years, most of the glass industry has switched from synthetically produced soda ash to that manufactured from a naturally occurring ore which does not contain chlorine. By 1977, more than 90 percent of the industry will be using natural soda ash(5,22).

Forming and Finishing

A wide variety of forming and finishing operations are used within the pressed and blown glass industry. Molten glass, properly conditioned, leaves the forehearth of the melting furnace as a single stream or is cut into individual "gobs" which are then transferred to a forming machine. Glass may be blown, pressed, rolled, or cast into a shape suitable for additional processing. After forming, glass may be surface treated, and sometimes fire-polished, after which it is passed through an annealing lehr. Once annealed, the glass article may undergo a variety of decorating, surface treatment, or coating operations.

Little data is available on emissions during the forming and finishing operations. However, compared to the melting operation thay are considered to be minor. These emissions can include: hydrocarbons emitted during forming operations; HCl and metal oxides emitted during surface-treatment operations; emissions associated with combustion gases produced during annealing; and hydrocarbons, lead oxide, HF, and NH_3 emitted during the finishing operations. Estimates that have been made of emissions from some of these operations are given in Table 8.

Forming

Gob shears, delivery chutes, and the forming molds for pressed and blown glass are lubricated with various solutions. These solutions can contain

TABLE 8. EMISSIONS FROM THE FORMING AND FINISHING OPERATIONS FOR ALL PRESSED AND BLOWN GLASS

Operation	Emission Factor[(a)], g/kg						Total Annual Emissions, Mg						Percent of National Emissions from all Stationary Sources	
	Hydrocarbons	HCl	Metal Oxides	Metal Chlorides	HF	NH_3	Hydrocarbons	HCl	Metal Oxides	Metal Chlorides	HF	NH_3	Hydrocarbons	Particulates
Forming	0.06 ±100%	0	0	0	0	0	178	0	0	0	0	0	0.001	0
Finishing	0	0.026 ±100%	0.016 ±100%	0.030 ±100%	1.04 ±100%	0.44 ±100%	0	7	7	10	103	20	0	Trace[(b)]
• Treatment	0	0.024 ±100%	0.016 ±100%	0.030 ±100%	0	0	0	7	7	10	0	0	0	Trace[(b)]
• Decorating	4.5 ±100%	0	0	0	0	0	456	0	0	0	0	0	0.002	Trace[(b)]
• Frosting	0	0	0	0	0.96 ±100%	0.44 ±100%	0	0	0	0	87	20	0	0
• Acid Cleaning	0	0	0	0	0.18 ±100%	0.44 ±100%	0	0	0	0	16	0	0	0

(a) Based on 2.97 Tg of pressed and blown glass produced annually (40 percent treated).

(b) Trace <0.0001 percent.

grease, oils, graphite, and silicone-based emulsions. In the past decade, there has been a transition from grease and oil lubricants to the use of silicone-emulsions and water-soluble oils (1 part silicone or oil to 90-150 parts water) on gob shears and gob-delivery systems.(5) Grease and oils are still utilized on molds. During forming operations, a visible puff of white smoke is formed when the molds are swabbed with a lubricating solution. Although this smoke dissipates in a few seconds, hydrocarbon vapors are probably released. The resultant emissions are probably drawn through the large ventilators on the roof of the plant.

Hydrocarbon emissions from the forming operation are estimated to be 0.06 g/kg, based on three point source measurements for soda lime glass. Data for other manufacturing lines are not available. Considering this rate as a worst case for the whole industry, total annual emissions would be 0.18 Gg, or 0.0006 percent of 1972 National emissions from stationary sources.(11)

Treatment

Pressed and blown glassware will occasionally receive a metal oxide (titanium or tin) surface treatment to improve resistance to scratching. In addition, this transparent treatment acts as a lubricant which can facilitate handling and shipping operations. The oxide treatment is obtained by subjecting the hot article (coming from the forming machine) to a vapor of metal chloride. This treatment is done within a hood. The metal chloride pyrolyzes to the metal oxide on the glass surface, leaving a metal-oxide film and releasing hydrogen chloride.

Emissions from the surface-treatment operation will consist of HCl, metal oxides, and hydrated-metal chlorides. Anhydrous tin chlorides which do not react with the glass will decompose by the action of heat and moisture within the exhaust ductwork to form metal oxides, hydrated metal chlorides, and HCl. Estimations based upon available data(23,9) indicate that approximately 60 percent of the total weight of the metal chloride input is released into the atmosphere. Using tin tetrachloride as the input material, these estimations indicate that of the total weight input, 14 percent is released into the atmosphere as a metal oxide, 27 percent as hydrated tin chloride, and 21 percent as HCl.

Emissions from the surface-treatment operation for glass articles were determined by engineering calculation to be 0.02 g/kg of tin or titanium oxide, 0.03 g/kg of hydrated tin or titanium chloride and 0.02 g/kg of HCl. Total annual emissions were estimated to be 6.9 Mg of metal oxide, 10.4 Mg of hydrated metal chloride, and 6.9 Mg of HCl. This worst-case estimate was based on 25 percent of the total melting output.

Annealing

Essentially all pressed and blown glassware undergoes an annealing operation, during which the glass is brought to a temperature (approximately 550 to 650 C) necessary to remove residual stresses and is subsequently cooled uniformly (to about 150 C) before the glass is removed from the annealing lehr (oven). Most lehrs are heated by natural gas.

The only emissions from annealing lehrs are combustion products. Since natural gas is used almost exclusively (some lehrs are electric) and the temperatures are relatively low, emissions are low. Measurement data are not available and emission rates are estimated on the basis of emission factors for the combustion of natural gas. These factors are given in Table 9. Total emissions are calculated on the basis of all product being annealed in gas-fired lehrs.

Decorating

Tableware, artware and novelties are often decorated with vitrifiable glass enamels or organic materials. A wide variety of decorating techniques are employed. Decorations are applied by brush, with stencils, banding machines, stamps, offset processes, electrostatically, and silk-screen priniting. Metallic decorating materials, such as gold, platinum and silver may also be applied. Emissions occur predominately from organic solvents and binders used in these decorative coating which are released during the curing of the compounds.

Approximately 30 percent of tableware and are glass are estimated to have decorative coating, amounting to 100 Gg of glassware decorated annually. Only one point source measurement is available. Considering a worst-case situation of 4.5 g/kg for HC emissions for decorating, the total HC annual

TABLE 9. EMISSIONS FROM THE ANNEALING OF PRESSED AND BLOWN GLASSWARE

Species	Emission Factor g/kg	Emission Factor (lb/ton)	Total Annual Emissions[(a)], Gg	(ton)	Percent of National Emissions From all Stationary Sources
NO_x	0.016	(0.032)	0.048	(43.5)	0.0003
SO_x	0	0	0		0
Particulates	0.0012	(0.0024)	0.004	(3.2)	Trace[(b)]
CO	0.0022	(0.0044)	0.007	(5.9)	Trace[(b)]
Hydrocarbons	0.0014	(0.0028)	0.004	(3.6)	Trace[(b)]

(a) Based on 3.0 Tg of glass processed.
(b) Trace <0.0001.

emissions would amount to 0.45 Gg of HC emitted which is 0.003 percent of national HC emissions from all stationary sources.(11)

Frosting of Light Bulbs

Electric light bulbs are frosted with a hydrofluoric acid-ammonia solution. Because of the corrosive nature of the fumes, this operation is carried out in hoods or fume chambers equipped with scrubbers. Emissions of HF and NH_3 vapors are always controlled by scrubbing. The controlled emission factor is estimated to be 0.96 g/kg for HF and 0.22 g/kg for NH_3. Total annual emissions are estimated to be 87.3 Mg of HF and 20.0 Mg of NH_3, even though no sampling data is available. This worst-case estimate is made (Appendix B) by assuming that the scrubber in a frosting operation is performing at an 80 percent efficiency, and that the amount of frosted light bulbs are 90.7 Gg annually. This data is extracted from that available on water pollution from the frosting operation.(24)

Acid Cleaning

The funnel and screen of television picture tubes are cleaned with a sulfuric acid/hydrofluoric acid solution before being joined together. The process generates HF fumes which are controlled by scrubbing. The controlled emission factor is estimated to be 0.18 g/kg and total HF emissions are estimated to be 16 Mg. Although no sampling data on air emissions is available, a worst-case estimate can be made using water pollution data,(4) as shown in Appendix B.

Emission Characteristics

Raw Materials Preparation

Emissions from this part of the manufacturing process will reflect the raw materials used (that is soda ash, limestone, feldspar, silica sand, borax, and the like) since no chemical reactions take place. Softer materials like limestone and soda ash will be more easily crushed to dust. Manufacturers usually specify particulate sizes ranging from 44 to 830 micron (+325 to -20 mesh). The primary ambient standard for particulate is 260 $\mu g/m^3$.

Glass Melting

At a glass plant, the majority of atmospheric emissions come from the melting furnaces. Calculations to portray the effect which a glass plant has on its neighboring air environments have been made in the following sections. Principal attention has been given to the pollutants issuing from the melting-furnace stacks. Emissions from the melting furnace consist of criteria pollutants such as NO_x, SO_x, particulates, CO and hydrocarbons, as well as borates, fluorides, lead compounds, selenium and some minor pollutants. These emissions contribute to photochemical atmoshperic reactions to produce smog and can be irritating to the lungs.

Particulates can vary considerably depending upon the glass composition being melted. For soda lime glasses, which comprise more than 75 percent of the glass produced by pressed and blown glass manufacturers, the particulates consist predominately (> 85 percent) of sodium sulfate. A clear guideline as to whether these sulfate emissions pose a health hazard is unavailable.

Forming and Finishing

Emissions from the forming and finishing operations consist of:

(1) NO_x, particulates, CO, and hydrocarbons emitted from gas-fired annealing lehrs.

(2) Hydrocarbons produced by flash vaporization of lubricants used in the forming region and those emitted from decorating operations.

(3) HCl, tin or titanium oxide, and hydrated metal chlorides exhausted from fume chambers during surface treatment operations.

(4) Fluoride or ammonia fumes from etching and acid cleaning operations.

(5) Other minor gaseous or particulate emissions associated with the wide variety of finishing operations described earlier.

Total nationwide emissions of the criteria pollutants produced in the different stages of the glass manufacturing process were listed previously in Table 2.

Ground-Level Concentrations

Ground-level ambient concentrations of pollutants were used in determining the environmental effects of the atmospheric emissions. They were calculated for representative operations used in the manufacture of pressed and blown glassware. The diverse nature of the pressed and blown glass industry precluded selection of process equipment which was representative of the entire industry, therefore several examples were calculated. Two soda lime glass furnaces, one having an annual production rate of 9.1 Gg and the other with an annual production rate of 29.9 Gg, were used in the calculations, along with a lead glass furnace having an annual production rate of 4.6 Gg. The furnace stack emissions were derived from the emission factors given in Table 7 and were applied to the annual production rates. Stack heights were 24.4 meters and 36.7 meters for the two soda-lime furnaces and 45.7 meters for the lead furnace. Tables 10, 11, and 12 list all the parameters for the melting furnaces, their stacks, and the ambient meteorology as used in calculating the ground-level pollutant concentrations. Stack heights for pressed and blown glass furnaces their stacks, and the ambient meteorology as used in calculating the ground-level pollutant concentrations. Stack heights for pressed and blown glass furnaces were prepared as Appendix C. They ranged from 8 to 53 meters, with the predominant height being about 20 meters.

The maximum ground-level concentration is used to determine information for the environmental effect criteria. This maximum concentration can be obtained from actual measurement or from a nomagraph for substitution into an equation. The equation is

$$X_{max} = \frac{2Q}{e\pi \bar{u} H^2} \frac{\sigma_z}{\sigma_y}$$

TABLE 10. PARAMETERS OF A SODA/LIME GLASS-MELTING FURNACE (8.1 Gg ANNUAL PRODUCTION) REPRESENTATIVE OF THE PRESSED AND BLOWN INDUSTRY AS USED IN ATMOSPHERIC-DISPERSION CALCULATIONS

Stack Parameters

Glass produced: 8.1 Gg/yr (9,000 T/yr)
Stack height: 24.4 m (80 ft)
Stack diameter: 0.85 m (2.8 ft)
Exit temperature: 204 C (400 F)
Gas flow rate: 710 m^3/min (23,000 ACFM)
Exit velocity: 21.0 m/sec (68.5 ft/sec)

Meteorological Conditions

Wind speed: at 10 meters -- 4.1 m/sec(a) (9.2 mph)
at top of stack -- 7.3 m/sec(b) (16.3 mph)

Ambient temperature at top of stack: 15 C (59 F)
Atmospheric pressure: 1000 millibars
Atmospheric stability: D(c)

Calculated Parameters

Plume rise: 8.8 m(d) (28.9 ft)
Effective stack height: 33.2 m (109 ft)

Estimated Parameter

Mean wind speed affecting the plume between the effective stack height and the surface: 6 m/sec

Emissions.(e)

NO_x: 1.09 g/sec (37.9 T/yr)
SO_x: 0.69 g/sec (23.9 T/yr)
Particulates: 1.34 g/sec (46.6 T/yr)
CO: 0.026 g/sec (0.39 T/yr)
Hydrocarbons: (0.039 g/sec (1.34 T/yr)
Selenium: 5.1×10^{-3} g/sec (0.018 T/yr)(c)

(a) Average of annual mean wind speeds measured at city airports near 30 glass-plant locations.

(b) Increase of wind with height in suburbs and level country as given in Figures 1-3 of ASME Recommended Guide for the Prediction of the Dispersion of Airborne Effluents, 1968.

(c) D stability is the predominant stability as determined from a cross section of Star Program results (see Table 14).

(d) Plume rise was calculated from the Holland equation for neutral stability.

(e) Worst case.

TABLE 11. PARAMETERS OF A SODA/LIME GLASS-MELTING FURNACE (29.9 Gg ANNUAL PRODUCTION) REPRESENTATIVE OF THE PRESSED AND BLOWN INDUSTRY AS USED IN ATMOSPHERIC-DISPERSION CALCULATIONS

Stack Parameters

Glass produced: 29.9 Gg/yr (33,000 T/yr)
Stack height: 36.7 m (120 ft)
Stack diameter: 1.8 m (6.0 ft)
Exit temperature: 399 C (750 F)
Gas flow rate: 341 m^3/min (12,000 ACFM)
Exit velocity: 2.24 m/sec (7.29 ft/sec)

Meteorological Conditions

Wind speed: at 10 meters -- 4.1 m/sec(a) (9.2 mph)
at top of stack -- 8.2 m/sec(b) (18.4 mph)

Ambient temperature at top of stack: 15 C (59 F)
Atmospheric pressure: 1000 millibars
Atmospheric stability: D(c)

Calculated Parameters

Plume rise: 2.99 m(d) (9.8 ft)
Effective stack height: 39.7 m (130 ft)

Estimated Parameter

Mean wind speed affecting the plume between the effective stack height and the surface: 6 m/sec

Emissions, (0)

NO_x: 4.03 g/sec (140.1 T/yr)
SO_x: 2.54 g/sec (88.3 T/yr)
Particulates: 4.95 g/sec (172.0 T/yr)
CO: 0.095 g/sec (3.30 T/yr)
Hydrocarbons: 0.142 g/sec (4.94 T/yr)
Selenium: 0.93×10^{-3} g/sec (0.067 T/yr)(e)

(a) Average of annual mean wind speeds measured at city airports near 30 glass-plant locations.

(b) Increase of wind with height in suburbs and level country as given in Figures 1-3 of ASME Recommended Guide for the Prediction of the Dispersion of Airborne Effluents, 1968.

(c) D stability is the predominant stability as determined from a cross section of Star Program results (see Table 14).

(d) Plume rise was calculated from the Holland equation for neutral stability.

(e) Worst case.

TABLE 12. PARAMETERS OF A LEAD GLASS-MELTING FURNACE REPRESENTATIVE OF THE PRESSED AND BLOWN INDUSTRY AS USED IN ATMOSPHERIC-DISPERSION CALCULATIONS

Stack Parameters

Glass Produced: 4.62 Gg/yr (5,100 T/yr)
Stack height: 45.7 m (150 ft)
Stack diameter: 1.5 m (5.0 ft)
Exit temperature: 466 C (870 F)
Gas flow rate: 654 m^3/min (23,000 ACFM)
Exit velocity: 6.17 m/sec (20.1 ft/sec)

Meteorological Conditions

Wind speed: at 10 meters -- 4.1 m/sec(a) (9.2 mph)
at top of stack -- 8.8 m/sec(b) (19.7 mph)

Ambient temperature at top of stack: 15 C (59 F)
Atmospheric pressure: 1000 millibars
Atmospheric stability: D(c)

Calculated Parameters

Plume rise: 5.72 m(d) (18.7 ft)
Effective stack height: 51.4 m (169 ft)

Estimated Parameter

Mean wind speed affecting the plume between the effective stack height and the surface: 6 m/sec

Emissions,( )

Particulates: 2.20 g/sec (76.4 T/yr)
Fluorides: 1.47 g/sec (50.9 T/yr)(e)
Selenium: 2.93 x 10^{-4} g/sec (0.010 T/yr)

(a) Average of annual mean wind speeds measured at city airports near 30 glass-plant locations.

(b) Increase of wind with height in suburbs and level country as given in Figures 1-3 of ASME Recommended Guide for the Prediction of the Dispersion of Airborne Effluents, 1968.

(c) D stability is the predominant stability as determined from a cross section of Star Program results (see Table 14).

(d) Plume rise was calculated from the Holland equation for neutral stability.

(e) Worst case.

where

X_{max} = maximum concentration (gm/m^3)

Q = pollutant emission rate (gm/sec)

$\bar{u}$ = mean wind speed (m/sec) at the height of the stack

H = effective stack height (m), the physical height of the stack plus the plume rise

σ_z = vertical plume standard deviation (m)

σ_y = horizontal plume standard deviation (m)

e = base of natural logarithms, 2.718

π = 3.14.

For stability Type D, the ratio $\frac{\sigma_z}{\sigma_y}$ is on the order of 0.5 varying from 0.57 to 0.24 between 0.1 km and 10 km downwind from a source$^{(25)}$. The ratio is approximately 1.0 for stability Type C. The maximum concentration occurs at a distance where $\sigma_z = H/\sqrt{2}$. Turner$^{(25)}$ has presented a nomagraph from which $X_{max}\ \bar{u}/Q$ and the distance to the point of maximum concentration can be determined for any stability and effective stack height. When emission rate and wind speed are known, the value of X_{max} can be calculated.

The environmental effects criteria are developed for 24 hr average concentrations, while the dispersion predictions discussed above are for short periods (3 to 10 min). For longer periods, one must consider that variations in wind direction and wind speed will cause the average concentration at a downwind monitor to be less than the concentration calculated for a short-term wind blowing constantly from the source to the monitor. Turner has given an equation by which the long-term average concentration can be estimated when the short-term concentration is known:

$$X_\ell = X_s \left(\frac{t_s}{t_\ell}\right)^b$$

where

X_ℓ = concentration for the long period (t_ℓ)

X_s = concentration for the short period (t_s)

t_ℓ = long-time period, min.

t_s = short-time period, min.

The value of the dimensionless exponent, b, is between 0.17 and 0.2

While this equation is most applicable for X_ℓ= 2 hr or less, it can be applied to a 24-hr period. Turner gives the conversion coefficient of 0.35 for transforming a 3-min average into a 24-hr average. Other conversion coefficients are 1 hr, 0.61, and 3-hr, 0.51.

Before calculating ambient pollutant concentrations, representative meteorological parameters for the area need to be chosen. These parameters, along with stack parameters, are required for determining plume rise and dispersion. Plume rise is calculated from the Holland equation:

$$\Delta H = \left(\frac{v_s d}{u}\right) (1.5 + \left[2.68 \times 10^{-3}\right] p \left[\frac{T_s - T_a}{T_s}\right] d)$$

where

ΔH = rise of the plume above the stack, m

v_s = stack gas exit velocity, m/sec

d = inside diameter of stack, m

u = wind speed at top of stack, m/sec

p = atmospheric pressure, millibars

T_s = stack gas temperature, K

T_a = air temperature, K.

Choices of the meteorological parameters are made after a review of climatology in some of the areas of the country where glass plants are found(26). Account is also taken of the variations of meteorology between the surface and the top of the furnace stack. The values selected for the melting-furnace calculations are listed in Tables 10, 11, and 12. Stability Type D (neutral class) is the most frequently occurring stability throughout the United States as calculated by the Turner method(25) which considers the surface wind speed and the net radiation (Table 13). A surface wind speed of 4.1 m/sec is chosen as representative of the conditions at the glass plants based on a survey of the average annual wind speeds listed for the National Weather Service meteorological stations(27) located at 30 cities which have glass plants. The reader should note that the 4 meter/sec wind speed in Turner's scheme for determining stabilities can accompany stabilities verying from Type B to Type E, depending on the solar radiation. Type D is chosen for the dispersion calculations on the basis of its predominant frequency. Wind speeds increase with altitude and this effect is taken into account for the effective stack heights of the representative furnaces. Wind speed in the layer in which the downward dispersion of the plume should take place, 0-33.2, 0-39.7, and 0-51.4 meters for the three furnaces, is estimated to be 6 meters/sec. This is an extrapolation from the standard wind-measurement height of 10 meters over suburban and level rural areas. For stack heights of 30 to 50 meters, the wind speed is expected to be 1.5 (level terrain) to 3 (urban areas) times stronger at the top of the stack than at 10 meters.

Table 14 (in its second column) presents the theoretical maximum pollutant concentration predicted for ground level in the vicinity of the glass-melting furnaces. These concentrations are the contributions from only the furnace and do not take into account other glass-plant emissions or emissions from sources other than the glass plant.

Emissions from two other sources representative of air emissions from a manufacturing operation in the pressed and blown glass industry were also considered in relation to their effect on ambient-air quality. These were:

(1) Particulates from a baghouse collecting the emissions from materials handling

TABLE 13. RELATIVE FREQUENCY OF ATMOSPHERIC STABILITIES[a]

Station	Stability Class				
	A	B	C	D	E and F
Milwaukee	0.001	0.031	0.094	0.636	0.238
St. Louis	0.005	0.047	0.103	0.555	0.289
Peoria	0.003	0.042	0.102	0.577	0.276
Pittsburgh	0.001	0.022	0.083	0.567	0.306
Columbus, O.	0.010	0.058	0.100	0.500	0.331
Mobile	0.008	0.052	0.115	0.453	0.371
Los Angeles	0.001	0.041	0.148	0.482	0.329
Dallas	0.004	0.042	0.107	0.586	0.262

(a) Based on Output from U.S. Department of Commerce National Climatic Center Star Program for Five Years of Data.

TABLE 14. MAXIMUM POLLUTANT CONCENTRATIONS AND SOURCE SEVERITY FOR EMISSIONS FROM REPRESENTATIVE PRESSED AND BLOWN MELTING FURNACES

Pollutant	Ambient Air-Quality Standard, ($\mu g/m^3$)	3-Minute X_{max}, ($\mu g/m^3$)	Adjusted[a] X_{max}, ($\mu g/m^3$)	Severity, S
	Soda/Lime Furnace -- 8.1 Gg Annual Production			
NO_x	100[b]	19.9	7.3	0.073
SO_x	365[c]	12.6	4.5	0.012
Particulates	260[c]	24.6	8.8	0.034
CO	40,000[d]	0.52	0.23	5.7×10^{-6}
Hydrocarbons	160[e]	0.72	0.36	2.3×10^{-3}
Selenium	0.67[f]	9.4×10^{-3}	3.4×10^{-3}	5.0×10^{-3}
	Soda/Lime Furnace -- 29.9 Gg Annual Production			
NO_x	100[b]	49.3	17.7	0.18
SO_x	365[c]	31.0	11.1	0.030
Particulates	260[c]	60.6	21.9	0.084
CO	40,000[d]	1.13	0.48	1.2×10^{-5}
Hydrocarbons	160[e]	1.74	0.88	5.5×10^{-3}
Selenium	0.67[f]	2.3×10^{-2}	8.4×10^{-3}	0.013
	Lead Glass Furnace -- 4.6 Gg Annual Production			
Particulates	260[c]	30.9	10.7	0.041
Fluoride	8.33[f]	20.5	7.4	0.89
Selenium	0.67[f]	4.1×10^{-3}	1.5×10^{-3}	2.2×10^{-3}

(a) 3-minute X_{max} adjusted to match sampling time of the standard using the following conversion factors from Turner[25]:

0.36 for 24 hours, 0.42 for 8 hours
and 0.51 for 3 hours.

(b) Annual arithmetic mean assumed here as 24-hr standard.
(c) 24-hr standard.
(d) 8-hr standard.
(e) 3-hr standard.
(f) Obtained from TLV x 8/24 x 1/100 where TLV = 2.5 mg/m^3 for fluoride and 0.2 mg/m^3 for selenium.

(2) Hydrogen chloride and titanium chloride from surface treatment operations.

To make the ambient-concentration estimates for these sources, emissions and stack parameters were adapted from data given in the NEDS listing(9). Meteorolgical conditions similar to those used in the glass-furnace emission-dispersion calculations were used for these other sources with adjustments for differing stack heights. Information regarding these calculations was prepared as Table 15.

For each of the maximum ambient concentrations that have been calculated, a source severity, S, is also determined. Source severity for criteria pollutants (particulated, sulfur oxides, nitrogen oxides, carbon monoxide, and hydrocarbons) is determined from the following equation:

$$S = \frac{X_{max}}{AAQS}$$

where

X_{max} = maximum average ground-level concentration of the pollutant for the time period of the standard ($\mu g/m^3$)

AAQS = ambient air-quality standard ($\mu g/m^3$).

For noncriteria pollutants, the source-severity equation uses the threshold limit value instead of the ambient air-quality standard with a correction for a 24-hour period and a safety factor:

$$S = \frac{X_{max}}{TLV\ (8/24)\ (1/100)}$$

where

TLV = Threshold Limit Values for each species

8/24 = Correction factor for the 8-hr work day which is the basis for the TLV

1/100 = Safety factor.

TABLE 15. MAXIMUM AVERAGE GROUND-LEVEL CONCENTRATION (X_{max}) OF SELECTED AIR POLLUTANTS FROM REPRESENTATIVE MATERIALS HANDLING AND TREATMENT OPERATIONS

Source 1. Baghouse Controlling Materials-Handling Emissions (98% Efficiency)

Materials Handled: 0.3 Gg/yr

Emission Point: Stack
height: 9.1 m; diameter: 0.5 m
exit temperature: 21 C; exit velocity: 10.3 m/s

Emission Factor: 1.91 g/kg
Emissions: 0.57 Mg/yr (0.63 ton/yr)

Species	X_{max} (3 min), μg/m^3	X_{max}, μg/m^3 (specified time)	Ambient Std μg/m^3	Severity Factor
Particulates	5.46	1.96	260	0.0076

Source 2. Surface Treatment of Glass

Production: 9 Gg/yr
Point of Emission: 13 m stack (no plume rise assumed)

Pollutants Considered	Emission Factor (g/kg)	Emissions
Hydrogen Chloride	0.02	5.71x10^{-3} g/sec (0.20 ton/yr)
Titatanium Chloride	0.02	5.71x10^{-3} g/sec (0.20 ton/yr)

Pollutant	X_{max} (3 min) μg/m^3	X_{max}, μg/m^3 (Specified Time)
Hydrogen Chloride	11.43	4.11
Titanium Chloride	11.43	4.11

Severity Factor Determination

Pollutant	TLV, mg/m^3	Severity Factor
Hydrogen Chloride	7	0.176
Titanium Chloride	10	0.123

A review of the source-severity factors in Tables 14 and 15 shows the highest value to be that produced by emissions of fluorides from a lead glass furnace, S = 0.89. The next highest source-severity factors is 0.18 for both nitrogen oxides emitted from a soda-lime furnace and hudrogen chloride from a surface treatment operation.

Affected Population

As a consequence of the dispersion of pollutants, the severity starts at zero near the stack, increases downwind, reaches a maximum, and then decreases to zero again (see Figure 10). The affected population is defined as the population around plant exposed to a severity greater than 1.0[28]. To determine the downwind distances enclosing the affected population, the standard dispersion equation for the centerline concentration from an elevated source is used.

$$X = \left(\frac{Q}{\pi \sigma_y \sigma_z \overline{u}}\right) \exp \left[-\frac{1}{2} \quad \frac{H}{\sigma_z}^{2} \right]$$

where

X = pollutant concentration at surface (gm^{-3})

$\overline{u}$ = average wind speed through the dispersion layer (m sec^{-1}). The winds from all directions are assumed to be euqally likely.

Other parameters are the same as in the earlier dispersion equation (page 58).

By rearranging, this equation becomes

$$\frac{X\pi\overline{u}}{Q} = \left(\frac{1}{\sigma_y \sigma_z}\right) \exp \left[-\frac{1}{2} \left(\frac{H}{\sigma_s}\right)^{2} \right]$$

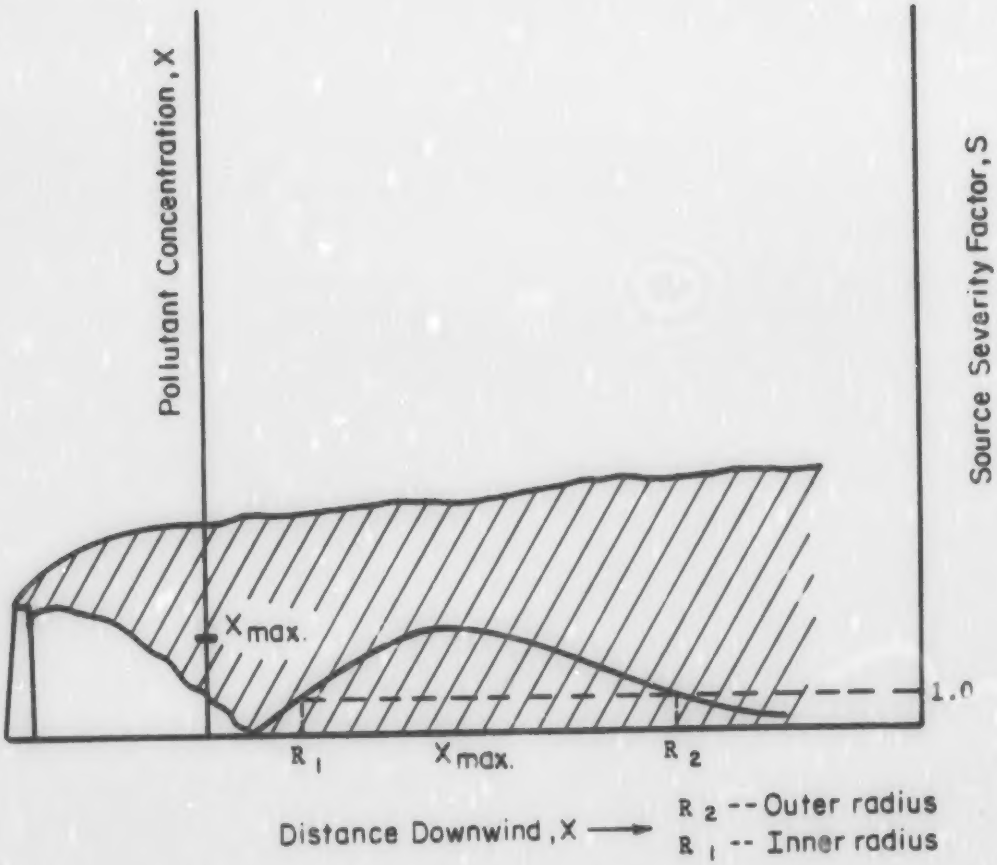
Pollutant Concentration, X
Source Severity Factor, S
X max.
1.0
R 1
X max.
R 2
Distance Downwind, X
R 2 -- Outer radius
R 1 -- Inner radius

FIGURE 10. ILLUSTRATION DEPICTING CALCULATION OF AREA WHICH CONTAINS THE AFFECTED POPULATION

A review of the source-severity factors in Tables 14 and 15 shows the highest value to be that produced by emissions of fluorides from a lead glass furnace, $S = 0.89$. The next highest source-severity factors is 0.18 for both nitrogen oxides emitted from a soda-lime furnace and hudrogen chloride from a surface treatment operation.

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Other parameters are the same as in the earlier dispersion equation (page 58).

By rearranging, this equation becomes

$$\frac{X\pi\bar{u}}{Q} = \left(\frac{1}{\sigma_y\sigma_z}\right) \exp \left[-\frac{1}{2} \left(\frac{H}{\sigma_s}\right)^2\right]$$

The value of X is specified by the requirement for S = 1.0 and then it is corrected to the three-minute average concentration which the dispersion equation gives. Substituting values of σ_y and σ_z from Turner's graphs of dispersion coeffiency as a function of distance downwind into the righthand side of the equation versus downwind distance. These values are plotted in a fashion similar to Figure 10 and the values of R_1 and R_2 are determined. These values form the inner and outer radii of an annulus enclosing the affected population.

Since no source severity factor for the pressed and blown glass industry was found to be greater than 1.0, no affected population calculation was made.

SECTION V

CONTROL TECHNOLOGY

Control of air emissions in the glass industry varies considerably, depending on the type, source, and amount of emission. Control technology has evolved for both economic and environmental reasons, and various methods are utilized to reduce air emissions from the different portions of the glass-manufacturing process. These methods include: (a) development of process modifications, (b) new furnace designs, and (c) application of control equipment. For example:

(1) Use of arsenic has been reduced for use as a fining agent.

(2) Many fossil-fuel-fired furnaces are equipped with electric boosting which can increase output, thus reducing the amount of effluent per unit of output. Some manufacturers have switched entirely to all-electric melting.

(3) Fabric filters, electrostatic precipitators, and scrubbers, are being used or have been examined for removal of particulates. In addition, several commercial equipment manufacturers are attempting to develop methods for removal of SO_x and NO_x emissions at the same time particulates are removed.

This section discusses the control technology currently being used or being considered for use by manufacturers of pressed and blown glassware. The study does not consider the economics or verify the control technology itself. Rather, this section identifies control technology reportedly applicable to the glass industry. The discussion is organized in a manner similar to the emission section.

Raw-Materials Preparation

The handling and mixing of raw materials is a source of particulate emissions from any glass plant melting such materials. Raw materials are normally conveyed (by screw conveyors, belt conveyors, bucket elevators, or pneumatic conveyors) from hopper railroad cars or trucks to elevated storage bins, as has been shown in Figure 3. Other glass-batch ingredients are delivered to the plant in paper bags or cardboard drums, and are later transferred manually to smaller storage bins or fed directly from the storage device.

Materials are gravity fed from the storage bins into weigh hoppers and then transported by transverse belts or bucket elevators into a mixer. Cullet is crushed to a desired size. After mixing, the glass batch is transferred to a charging bin located next to the glass-melting furnace or into a batch storage bin, depending upon the design of the batch-handling system. Positive displacement or vibratory feeders at the bottom of the bins feed the materials to the chargers, where it is fed into the glass-melting furnace. Cullet may be added to the batch in the mixer, while the batch is being transferred, or charged separately to the melting furnace(29).

Emissions

Little information is available regarding plant emissions due to dusting during the raw-materials handling stages of the process. As discussed in the previous section, the fraction of the dust generated which leaves the plant site will consist of particles smaller than 100 microns in diameter. Also, as described in the previous section on emissions, the particulate emission rate for raw-materials handling is estimated to be 1.5 g/kg. Based upon the total glass batch handled by the pressed and blown glass industry, annual particulated exhausted are estimated to average 6.26 Gg.

Information on the composition of these particulate emissions is not available, but they will consist essentially of the same raw materials being handled (soda ash, silica sand, limestone, etc.), since no chemical reactions occur during this portion of the manufacturing process. Softer materials (e.g., ash) can be expected to predominate. Glass manufacturers will generally use raw materials which are coarser than 44 micron, as shown in Table 16. Pressed and blown glass manufacturers use a greater percentage of raw materials finer than 100 microns. Even still, uncontrolled emissions should not exceed 5 percent of the total materials handled. The amount of raw material emitted from the plant site due to inertial forces alone would be relatively small, as reported measurements indicate(9).

Raw-Materials-Control Technology

Process Modifications or Materials Selection.

Manufacturers of pressed and blown glassware will generally minimize dusting problems in batch-handling operations by limiting the amount of fine particles (<100 microns) in the batch material. Specifications for glass-grade raw materials will generally require removal of the finer sizes of material, especially with softer materials that tend to be crushed to dust easier than sand.

Another batch-preparation method that is used to control dusting during handling is the addition of water to the raw batch (batch wetting). Trials have also been conducted during which the batch is wet with a liquid caustic-soda solution that is substituted for soda ash(4). Water is presently added in amounts up to 4 percent to the mixed batch materials. The substitution of a caustic-soda solution for a soda ash is not generally practiced by the glass industry(4,30).

At those points in the raw materials handling and preparation stage where dust may be generated, control is accomplished through the use of collection equipment. This is almost always done with fabric filters (e.g., baghouses).

Efficiency of Control Equipment.

Transport of raw materials in railroad hopper cars and hopper-bottom trucks (dump trucks) is still practiced. During unloading of these trucks or railroad cars, the dumping of materials onto conveyor belts can result in some dust being dispersed into the air. Generally, the hopper cars or trucks are connected to sealed receiving hoppers with fabric sleeves and the dust generated during the unloading operation is filtered through the sleeves or exhausted through a baghouse(31,32). Enclosing the loading area with a suitable fabric structure and sealing all covers and access opening with gaskets is effective in reducing dust during this operation.

TABLE 16. GLASS-GRADE PARTICLE-SIZE SPECIFICATIONS FOR SAND, LIMESTONE, AND 10- AND 20-MESH DOLOMITE

Approximate Particle Size	U.S. Standard Mesh Size	Glass-Grade Sand, %	Glass-Grade Limestone, %	Glass-Grade Dolomite, %	
				10-Mesh	20-Mesh
2.3 mm	Cum retained on 8	-	0.0	0.0	0.0
1.3 mm	Cum retained on 16	-	2.0 max	15.0 max	-
820 µ	Cum retained on 20	0.0	10.0 max	-	2.0 max
410 µ	Cum retained on 40	12.0 max	-	-	-
150 µ	Cum retained on 100	-	-	90.0 min	80.0 min
105 µ	Cum retained on 140	92.0 min	85.0 min	-	95.0 min
74 µ	Cum retained on 200	99.5 min	94.0 min	97.0 min	96.0 min
44 µ	Cum retained on 325	100.0 min	-	-	-

This results in an inward-air velocity across the open mouth of the bag that prevents an eruption of dust into the atmosphere(32). Trapped air and fine dust can then be filtered by a conventional fabric filter and the cleaned air exhausted into the atmosphere.

Weigh hoppers and mixers require ventilation because of surges in material from the large air flows. In older mixers, polyvinylchloride seals are generally installed between the rotating body of the mixer and its frame to reduce air leaks. In newer mixers, the body does not rotate. The exhaust gases are usually filtered of particulates greater than submicron size by the use of fabric filters.

The use of fabric filters for separation of particulates from air has been practiced for a number of years in the glass industry. The earliest fabric filters were known as "baghouses", since they were large free-standing units for exposed fiber bags. By passing the exhaust air through layers of a woven fabric, the particulates were collected. Unfortunately, as the thickness of the collected layer of particulates increases the pressure differential required for continued air flow also increases. Thus, the collected dust must be periodically removed by manual or mechanical shaking. Almost all container glass plants use fabric filters to remove entrained dust particles(9,33). The fabric filters used today are totally enclosed, and most have a continuous removal operation for the trapped particulates. The traditional woven and synthetic fabrics are used. Today, fabric filters are generally made of low-temperature materials such as Nomex, nylon, terylene, or Orlon(31,32).

Fabric filters are used to collect particulates from the raw-materials and handling operations for several reasons. First, they have an efficiency of greater than 99 percent and they can be used to collect fine particulates. In addition, the trapped particulates can sometimes be recovered for reuse or recycle(5,31,32). One manufacturer has from 2 to 6 baghouses with a stack height less than 50 feet at a plant manufacturing 72.6 Gg (80,000 tons) of container glass per year(9,33). They used nylon-fabric filters operating at 98 percent efficiency and collecting about 36.3 kg (80 lb) of dust per year.

Glass-Melting Operation

In a glass-melting furnace, raw materials and cullet are heated until a homogeneous, viscous liquid, free of gas inclusions, is formed. Temperatures in the melter will generally be in the range of 1500-1600 C (2730 to 2913 F)(34). Natural gas and fuel oil are the principal types of fuel, with natural gas predominating (60-65 percent)(1,35). Over 80 percent of glass-melting furnaces have regenerative firing systems for purposes of heat recovery and fuel conservation(9). To increase melting capacity, many furnaces now have electric-boosting systems. These systems consist of several water-cooled electrodes euqally spaced along the sides or bottom of the melter, below the surface of the glass.

Additionally, all-electric melting furnaces are utilized by portions of the pressed and blown glassware industry. With all-electric melting, the glass is heated by its own self-resistance by passing an electric current through it. Electric melters currently melt less than 10 percent of the glass in the United States(37). This type of melter contains a blanket of glass batch which covers the entire surface of the molten glass. Any volatiles are almost entirely trapped by the glass batch as they percolate up through the batch blanket especially when borosilicate and opal glasses are being melted. Electric melting offers somewhat less of an abatement advantage for the melting of soda-lime glass.

Emissions

Major criteria air emissions from a glass-melting furnace consist of NO_x, SO_x, HF, and particulates. Other emissions include CO, hydrocarbons, and selenium.

Nitrogen oxides represent the second largest fraction by mass, about 21 percent of glass-furnace emissions(10,36). As described earlier, the source test measurements of NO_x emission rates vary from 0.41 to 10.0 g/kg of glass produced. Based on an average emission rate of 4.25 g/kg, glass-melting furnaces with a total production rate of 2.8 Tg would emit 9.5 Gg of NO_x yearly.

SO_x emission, on the other hand, is dependent primarily upon the sulfur content of the fuel and, to a lesser extent, on the sulfur content of the batch material. Sulfur present in the fuel oil will oxidize and appear as SO_x in the exhaust gas. A fuel oil containing 1 percent sulfur by weight emits ∿ 600 ppm SO_2 in the flue gas(13). Sulfur can also be present in the batch materials, usually as Na_2SO_4. During heatup, the sulfate decomposes and sulfur dioxide forms, some of which is chemically incorporated into the glass (as SO_3^-) and some of which is released within the furnace. An average emission rate of SO_x for soda lime glass is 2.68 g/kg. Thus, plants melting 2.24 Tg of glass annually would emit approximately 6.0 Gg of SO_x yearly.

HF is emitted from opal and certain lead and borosilicate glasses. The emissions result from the decomposition of fluoride bearing batch materials. A portion of the fluoride (∿ 40 percent) remains in the glass, the remaining being emitted as HF gas or as a fluoride compound. The quantity of HF emitted depends on the glass batch composition and the furnace operating parameters. The uncontrolled average total fluoride emission rate is estimated to be 10.0 g/kg, with annual emissions of 2.5 Gg of F^-.

Particulate emissions from a glass-melting furnace result primarily from volitization of materials in the melt that combine with gases such as SO_3 or HF to form condensates in the flue system. Particulate emissions from soda lime glass consist of approximately 80 percent sodium sulfate(5,10,18,19). These particulates form from the condensed vapors in the melt and are submicron sized (6,18-21), with the median particle diameter being about 0.13 μ(19,20). Larger sized particles are generally retained in the regenerative system (30,34). Particulates from other glass types are somewhat less defined. They can include NaF, B_2O_3, PbO, $PbSO_4$, and Na_2SiF_6, depending upon the glass type. Particle size distributions are not clearly defined, but the average size is generally less than 2 micron(20,21). Source-test measurements for particulate emission rates vary from 0.49 to 12.57 g/kg of glass produced, which average to a particulate emission rate of 5.22 g/kg.

Carbon monoxide is exhausted from the glass-melting furnace, primarily as a result of incomplete fuel combustion. Source-test measurements have reported emission rates from 0.09 to 0.15 g/kg. An estimated average emission rate is 0.10 g/kg.

Hydrocarbons are also formed in the glass-melting furnace as a result of incomplete fuel combustion. Source-test measurements have reported emission rates from 0.02 to 0.27 g/kg. The calculated average emission rate is 0.15 g/kg. Actual emission rates are a function of firing conditions (extent of fuel/air mixing, excess air, firing temperature).

Selenium is generally used in amounts of 2 weight percent or less in the soda-lime glass batches as a decolorizer to neutralize the green tint in glasses caused by iron impurities. No test measurements on actual selenium emissions have been reported, but it likely leaves the stack as selenium vapor because of its low vaporization temperature (315 C for SeO and 685 C for Se)(5,18). Based on an average production of 1.8 Tg (2 million tons) of glass, an average emission rate for selenium has been calculated to be 0.002 g/kg.

Glass-Melting-Control Technology

Control of emissions from the glass-melting furnace has occurred for both economic and environmental reasons. Five general approaches have been employed:

(1) Modification of feed material
(2) Modification of furnace design, including electric melting
(3) Increase of checker volume
(4) Adoption of commercial-control apparatus
(5) Modification of furnace operation.

Modification of feed material, furnace design, and furnace operation have been used primarily to control gaseous emissions, while the other methods have focused on control of particulate emissions.

Modification of Feed Material. Some of the glass batch raw materials have a tendency to vaporize or decompose in the glass-melting furnace (e.g., fluorides, nitrates, and selenium). By minimizing the amount of these or other ingredients used or by substitutions of other materials, the volume of gaseous emissions exhausted from the glass-melting furnace can be reduced. For example, the use of arsenic as a fining agent has been reduced and changes have been made to produce fluoride-free glass batches. Cerium is used to partially replace selenium as a decolorizer. In addition to reducing the selenium in the batch (by about 40 percent), this modification leads to the elimination of arsenic in the batch, since cerium and arsenic are not compatible. Cerium is especially appealing because it tends to form high-melting compounds which do not readily vaporize.

Modification of Furnace Design. Increasing the fuel efficiency of the glass-melting furnace can in turn lead to a decrease in combustion products, a decrease in dust entrainment by hot combustion gases passing over the melting glass batch, and possibly a decrease in furnace temperature. In addition, emissions from low melting and easily vaporized fluxing or fining agents can be lowered. Several methods currently in practice to improve furnace efficiency are:

(1) Better instrumentation for regulating air/fuel mixtures and monitoring furnace temperature and stack gas composition.
(2) Combustion control to produce long luminous flames that eliminate spurious hot spots in the furnace and provide better heat transfer to the melt.
(3) Improved refractories to increase corrosion resistance, which permits furnaces to be more fully insulated.
(4) Use of electric boosting to increase furnace capacity, increase furnace efficiency, and lower temperatures above the molten glass.

All of these methods have been employed to control gaseous emissions. Sulfur oxides that form can be controlled by both limiting the sulphate in the feed material and by the improvement of furnace efficiency. Ryder and McMackin(10) have found that the SO_x emission rate increases directly with an increase in production rate on a sideport furnace melting soda lime glass. This increase is attributed to the higher temperatures needed (1552 C versus 1460 C) (2825 F versus 2660 F) when the daily production rate is doubled to 181 Mg (200 tons).

NO_x emission can be also lowered when the furnace efficiency is increased if the furnace temperature also drops. A 10 percent decrease in fuel consumption can cause a 10 percent decrease in NO_x emissions(17,21).

Electric boosting is commonly used on fossil fuel-fired furnaces in the container glass industry, primarily to increase output. Boosting can result in a reduction in emissions per unit of output.

Electric Melting. These furnaces are used to essentially eliminate both particulate and gaseous emissions from the glass-melting operation. As discussed previously, the cold batch covering the glass traps the majority of these emissions. In a fossil-fuel fired melter, volatilization occurs at the interface between the hot glass and the combustion gases. This condition does not exist in the all-electric melter, and consequently this source of emissions is elimated also.

Electric melting is utilized to a much greater extent in the manufacture of pressed and blown glassware than with container glass because higher quality glass can be produced at virtually zero emission rates. It is not used to make flat glass because furnace sizes are more incompatible. Electric melting does have certain operational and control problems, and experience with large melting units (> 120 Mg) is essentially nonexistent. Because of capital considerations and the higher cost of electricity, electric melting is often not judged to be economical. In recent years, the need to control emissions has made the use of electric melting more economically appealing for non-soda-lime glasses. However, in 1975, less than 5 percent of the glass manufactured was made by electric melting(37).

Adoption of Commercial-Control Apparatus. Particulates can be cleaned from the glass furnace exhaust by scrubbers, fabric filters, or electrostatic precipitators (ESP). Scrubbers can also be used to collect SO_x emissions, while fabric filters and ESP's only remove particulates. Teller(21,38) suggests spraying the stack gas with an alkaline solution, causing the acidic gases (SO_x, HF, of HCl) to react and form particulates that can then be collected by the control device.

Scrubbers. One type of particulate scrubbing is a two-step process. Initially, particles in the exhaust gases are "contacted" or wet by a scrubbing fluid that draws the particles into agglomerates. These agglomerates are then separated from the gas stream by an inertial mist-elimination process.

A low-pressure (< 10-in. water) centrifugal scrubber used by the Thatcher Glass Company in Saugus, California(5) had two separate contacting sections within a single casing. Separate 50.7 metric horsepower (50 horsepower) circulating fans forced dirty gas through each section containing two to three impingement elements similar to fixed blades of a turbine.

One reference(39) mentions a scrubber that uses a packed-bed preconditioning chamber. Hot gases (538 C) containing volatized sodium compounds enter the chamber, while the vapors condense out onto the packing material. This material is wet by a scrubbing solution and provides a large surface area for condensation. A standard Venturi-type scrubber completes the system. This scrubber is presently installed on a 0.181 Gg/day (200 ton/day) container (soda-lime) glass furnace and it reduces particulate loading from more than 0.23 to less than 0.046 g/sdm^3 (from more than 0.10 to less than 0.02 g/sdcf)(39).

One soda-lime glass manufacturer(40) installed a tower scrubber (2.9-meter diameter) on a 44.8 meter^2 (482 ft^2) melter. Hot effluent from the furnace is initially quenched and saturated with a caustic solution passing through the exhaust gas at 900 gal/min. The gas then passes into a 300 gal/min variable throat Venturi operating at 30 in. of water. This scrubber has been plagued by malfunctions and breakdowns. A highly visible steam plume is exhausted when it is not working.

Fabric Filters. Fabric filters, also known as "baghouses"(34), collect particulates by filtering exhaust gas from glass-melting furnaces through closely woven natural or synthetic fabric filters that are capable of trapping submicron particulates. Unlike wet scrubbers, fabric filters are less affected by variations in the gas flow rate. Temperature control, however, is very critical for proper functioning and the type of fabric filter selected is dependent upon the temperature of the exhausted gases. Fabric filters are generally made of cotton sateen, standard nylon, wool, dacron, orlon, NOMEX, teflon, and fiberglass(32,34). Maximum operating temperatures for these fabrics are given in Table 17. Since stack gas from a glass melting furnace is at 316 to 645 C (9600 to 1200 F)(21), the gas must be cooled to a temperature compatible with the fabric filter bag. This cooling can be accomplished by using the following methods, either alone or in combination:

TABLE 17. MAXIMUM USE TEMPERATURE FOR VARIOUS FABRIC-FILTER MATERIALS

Fabric	Maximum Temperature	
	F	C
Cotton Sateen	190	88
Standard Nylon	200	93
Wool	225	107
Dacron	275	135
Orlon	275	135
Nomex	400	204
Teflon	450	232
Fiber Glass	550	288

(1) Air dilution
(2) Radiation-cooling columns
(3) Air/gas heat exchangers
(4) Water-spray chambers.

Dilution of off gasses with air is the simplest and most trouble-free method for reducing temperature, but requires the largest baghouse because of the increased volume of gases. Air-to-gas heat exchangers, and radiation and convection ductwork are subject to fouling from dust in the effluent. A water-spray increases humidity and requires careful temperature control to avoid condensation, but it does permit use of smaller baghouses. Care must be taken with all of these methods to avoid cooling the gas to the temperature where SO_3 and H_2O will combine and condense, fouling or reacting with the fabric filters. In addition to being selected for their thermal compatibility, fabric-filter bags must also be corrosion and abrasion resistant. Cotton, orlon, and dacron can deteriorate from the SO_3 in the flue gas$^{(22)}$.

A fabric filter air-pollution control system was installed in 1974 on a 41.8 m^2 (450 ft^2) melter producing soda-lime glass$^{(40)}$. The 482 C (900 F) effluent from the furnace was initially cooled to 177 C (350 F). A fine powder aluminate precoat was then introduced into the air stream at 18.1 kg/hr (40 lb/hr) along with ambient air, further reducing the gas temperature to 121 C (250 F). The baghouse contained 1200 m^2 (12,915 ft^2) of dacron-filter cloth divided into six compartments, each containing 900 filter bags. During normal operation, the air-to-cloth ratio was 1.55, but this increased to 1.86 during the cleaning cycle. The pressure drop across the bags ranged from 3.5 to 4.5 in. of water. An exhaust blower had to develop 16 to 18 in. of water pressure to overcome the resistance of the checkers, heat exchanger, baghouse, and about 46 meters of duct. Initially, the heat exchanger required maintenance about 15 percent of the time due to plugging with material condensing from the gas stream. By blocking off about 40 percent of the tubes, a normal maintenance schedule was used, but the temperature increased slightly. Discharge of particulates from the baghouse outlet was typically 1.1 kg/hr (2-3 lb/hr). Tests using a Brinks Impactor showed these particulates to be < 0.75 micron.

Electrostatic Precipitator (ESP). In an electrostatic precipitator (ESP), a voltage source creates a negatively charged area, usually created by hanging wires in the gas flow path. Grounded collecting plates composed the sides of the ESP. A pwerful electric field is created by the high potential difference between these grounding plates and the discharging wires. As the gas stream passes through the field, the particles become electrically charged and are drawn to the collecting plates. Periodically, accumulated particles are removed from these plates by vibration, rapping, or rinsing. Thus, by applying the collecting force only to the particles to be collected, a much lower power input is required (i.e., 200 watts per 0.5 m^2/s)(30).

NAFCO Engineering, Ltd. (a Japanese firm) has developed a new type of ESP. In contrast to the conventional units, the NAFCO ESP uses thousands of stainless steel needles affixed to the leading and trailing edges of positively charged electrode plates. Thirty-five of these systems are now in operation in Japan, with nine of them being used on soda lime glass-melting furnaces(20) and the remaining on other pressed and blown type glasses. United McGill Corporation, who is the licensed United States distributor for the NAFCO ESP, has installed the unit on 20 pressed and blown glass furnace to date(41). All of these systems have an outlet particulate loading of < 0.046 g/std m^3 (0.02 g/scfd) or less.

An 84.4 m^2 (908 ft^2) melting furnace, used for producing soda lime glass, had an ESP installed in early 1974(40). It consisted of dual chambers, in which the air flow could be directed to either chamber or divided between them. Each chamber had three electrical fields connected in series. Designed for 12.9 sec. treatment time at 0.67 m/s (2.2 fps) velocity through the treater, one chamber was found to be as effective as two, the conclusion being that the system was over-designed.

Other Technology. Collector systems previously discussed are primarily useful for collecting particulates and for decreasing opacity of gaseous emissions. One company now offers dry and wet systems(4,21,38) to control both particulate and gaseous emissions. A nucleation scrubber is used on their wet system to effect collection of submicron particulates and acidic gases (HF and SO_x). A solid absorbent, on the other hand, is injected into the gas stream to react with the noxious gases in their dry system. The absorbant is then separated from the gas along with particulates in a fabric filter.

A patent (U.S. 3,789,628) was issued for a scrubber in which an aqueous solution of sodium silicate is sprayed into the gases as they are exhausted in the furnace stack. Water from the solution evaporates in the gas stream and the sodium silicate forms a small sticky sphere which can react chemically with NO_x, SO_x, and physically with particulates. These spheres can then be collected and recycled into the glass batch(42).

The quantity of NO_x from a glass-melting tank was studied by Kitayama, et al.(43), to evaluate methods for reduing fuel consumption under photochemical smog warnings. A glass-melting furnace (of unknown glass composition) with a 154.2 Gg/day (170 ton/day) capacity using preheated air at 1100C, emitted 850-1000 ppm of NO_x. By varying the damper opening and reducing the excess air by 10 percent, the NO_x emissions were reduced to 480 ppm. When the excess air was reduced 20 percent, the NO_x emissions were reduced to 45 ppm.

Takasaki(44) developed a method for removing NO_x from flue gases by wet oxidation and absorption. This technique appeared to eliminate more than 90 percent of the NO_x from the flue gas of a glass-melting furnace. By using activated carbon and chlorine acid soda, a pilot plant with 51 kg m^3/hr reduced its NO_x emissions by 95 percent. This system consisted of a special liquid-gas contact tower that utilizes a chlorine dioxide and chlorine oxidizing agent known as Fujinon-Ox to convert No into NO_2 which was absorbed by a liquid and stabilized. The exiting gas contained no NO. < 10 ppm NO_2, < 5 ppm SO_2, no chlorine oxide, chlorine, or hydrogen chloride, 13 percent CO_2, 3.5 percent O_2, and 0.03 mg/kg m^2 of dusts. Other details were not reported.

Kanematsu(45) reports on scrubbers handling 377, 7.1, and 28.6 kg m^3/hr of SO_x in the flue gas. By using a wet or dry desulfurization method whereby the sulfur oxides are absorbed by NaOH solutions and oxidized in air, the SO_x can be recovered as mirabilite. Kanematsu(46) also suggests use of low sulfur fuels, high stacks, and stack-gas desulfurization systems as method for controlling SO_x emissions.

Efficiency of Equipment

Least effective of the air-pollution control devices is the wet scrubber(40). In addition to being subject to numerous malfunctions and breakdwons, they have been found to exhibit particulate-collection efficiencies as low as 66 percent(40) to as high as 90 percent(30) (if gain loadings are low). By fitting the column with impingement plates, efficiency can range up to 95 percent with particles as small as 5 microns(30). A major advantage of this system is its ability to remove acidic gases.

Baghouses have a reputation for high efficiency and dependability. Fabric filters are capable of > 99 percent efficiencies and can collect particulated to below 0.75 micron(30,40). Major disadvantages are that exhaust gases must be pretreated to remove gaseous emissions and must be cooled before they contact the low-temperature fabrics.

Electrostatic-precipitator performance is highly sensitive to temperature and volume fluctuations. Electrical characteristics of particulates, which affect collection efficiency, vary with temperature, humidity, SO_2 content, and the type of particulate. Conventional ESP's have been shown to have efficiencies up to 95 percent and collect particulates doewn to submicron size. The NAPCO ESP, on the other hand, has a reported outlet loading of less than 0.046 g/std m^3 (0.02 grains/scf)(20). For an uncontrolled emission rate of 1 kg of particulate/Gg (2 lb of particulate/ton) glass and an air flow of 3119 std m^3/Gg (100,000 scf/ton), the efficiency will be 85 percent. For an emission rate of 10 kg/Gg (20 lb/ton), the efficiency will be greater than 98 percent. This ESP is designed so additional sections can be added and efficiencies greater than 99 percent can be obtained(30,47).

Wet or dry desulfurization methods, presently in use by one glass company in Japan, have shown respective efficiencies of better than 97 and 80 to 90 percent for the wet or dry SO_x removal(45).

Forming and Finishing

As the glass leaves the forehearth of the melter, it is normally cut into "gobs" by a pair of mechanical shears. Chutes direct the gobs from the feeder into blank molds where it is formed by one or two methods. The glass can also be cats, drawn, or rolled after it exists from the forehearth. The gob is usually pressed or blown into its final shape.

As discussed in an earlier section, a wide variety of forming and finishing steps may be employed, depending upon the product desired. These steps can include surface treatment with a metal chloride, fire-polishing with an oxygen-gas flame, decorating with enamels or organic base colors, and coating with an organic material. All of the glass is heat-treated for purposes of crystallizing the glass when appropriate and annealing thermally induced strains from the glass.

Forming Emissions

Molds on forming machines, gob shears, and delivery chutes are lubricated with solutions ranging from grease and oils to graphite and silicone-based emulsions. During the past decade, silicone emulsions and water-soluble oils have replaced some grease and oil lubricants on gob shears and gob-delivery systems(5). Grease and oils are still used on molds and cause white smoke emulsions during flash vaporization of the swab. Although the smoke dissipates in a few seconds, hydrocarbon vapors are released. These emissions are released inside the plant since hoods are not used to vent the hydrocarbons outside. Source tests indicate the rate of emission for hydrocarbons is 0.06 g/kg. Total annual emissions for the industry are calculated to be 0.23 Gg.

Forming and Finishing Control Technology

Efforts to control the hydrocarbons emissions have centered on finding lubricants capable of withstanding high temperature (1100 C [2200 F]) without volitalizing. Use of silicone emulsions and water-soluble oils (90 to 150 parts of water to 1 part oil or silicone) can eliminate these emissions. Unfortunately, they have not performed well as mold-release compounds(5). Emissions from the forming machinery are dispersed within the plant and exhausted by the room ventilating systems. No manufacturers have been identified as using a control device for these emissions.

Decorating

Emissions. Hydrocarbon emissions from organic solvents and binders used in coatings on containers are released when decorative coatings are cured in annealing lehrs. A worst case emission rate for these hydrocarbons is 4.5 g/kg.

Control Technology. Process modifications are difficult difficult to accomplish without harming the quality of the coating(48). In addition, they do not completely eliminate hydrocarbon emissions. Several such changes involve the substitution of solvents and a reduction of solvent concentration in the coating. Hydrocarbon emissions can be controlled by incineration, absorption (activated charcoal or silica gel), or condensation(48).

Frosting of Electric Light Bulbs

Emissions. Hydrofluoric acid (HF) and ammonia (NH_3) emissions occur in the frosting of electric light bulbs. The controlled emission rate is estimated to be 0.96 g/kg of HF and 0.22 g/kg of NH_3, assuming an 80 percent efficiency of control equipment.

Frosting Control Technology. Scrubbers are used to control emissions from these operations. Efficiencies are reported to be on the order of 80 to 90 percent(24).

Acid Cleaning

Emissions. In certain segments of the pressed and blown glass industry, acid cleaning (sulfuric acid and hydrofluoric acid) is done to prepare parts for further processing and HF fumes are generated. Using available water pollution data(24), the emission rate for HF is estimated to be 0.18 g/kg.

Control Technology. Scrubbers are utilized in this area and reportedly operate at an efficiency of 80-90 percent(24).

Surface Treatment

Emissions. Emission from the coating of glass products with tin or titanium tetrachloride include both particulates (tin chloride, tin oxide) and gases (tin compounds, HCL, Cl_2). Chlorine and unreacted metal chloride are released into the atmosphere. The emission rate is estimated to be 0.02 g/kg of metal oxides, 0.03 g/kg of hydrated metal chlorides, and 0.02 g/kg of HCl. Exhausted particulates are generally composed of submicron-sized tin chloride and tin oxide.

Coating Control Technology. One patent (U.S. 3,789,109)(49) has been issued for an apparatus to be used for cleaning solid, liquid, and gaseous pollutants from a hot-end coating station of a glass manufacturing plant. Glass is coated with an external metallic coating to reduce breakage. Because most of the anhydrous stannous chloride used does not adhere to the glass but discharges through the air-exhaust system, a potential pollution problem is created. In this apparatus, the air is heated until the metallic chlorides disassociate to metallic oxides and hydrogen chloride gas. Exhaust gases are then sprayed with fresh water to cool th- stream with the water reacting with the hydrogen chloride to form hydrochloric acid. Exhaust air passes into a scrubber in which the pollutants are removed.

SECTION VI

FUTURE PRODUCTION OF PRESSED AND BLOWN GLASSWARE

The pressed and blown segment of the glass industry produces a diverse and always changing spectrum of glass products. Portions of the industry manufacture products for direct consumer use (e.g., tableware and artware) while other portions manufacture products key to other industries (automotive, electronic, medical, etc.).

Future production is tied very much to the general growth of the economy. For instance, recent downturns in the purchase of television sets has resulted in severe curtailment in that portion of the industry which produces lead glass. The projected growth rates for pressed and blown glass is estimated to be between 3 and 4 percent through 1980(50).

The shortage of natural gas and the allocation of petroleum products have placed some constraints on production, which would have been more severe if the economy were not in a somewhat depressed state. The industry has historically been very dependent on the use of natural gas. Oil is the normal replacement fuel, for which the industry does not have an historical use pattern.

The industry is research oriented and many new products exist today which were still in the laboratory ten years ago. Fiber optics is one such product, which potentially could replace all major communications lines within the next decade.

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APPENDIX A

GEOGRAPHICAL LISTING OF PRESSED-AND-BLOWN GLASS PLANTS

TABLE A-1. GEOGRAPHICAL LISTING OF THE 176 PRESSED AND BLOWN GLASS PLANTS

State	Plant	City	County	AQCR	County Population Density, persons/km^2 (persons/mi^2)	Furnaces
Arkansas	Scott Depot Glass Co.	Fort Smith	Sebastian	17	57 (148)	4
	Thomas Ind., Inc.	Fort Smith	Sebastian	17	57 (148)	18
California	Arrowhead Puritas	Gardena	Los Angeles	24	662 (1715)	1
	Brock Glass Co.	Santa Ana	Orange	24	696 (1803)	2
	Glass Works, Inc.	Huntington Beach	Orange	24	696 (1803)	6
	Owens Illinois	City of Industry	Los Angeles	24	662 (1715)	
	Pacific Glass Works	Huntington Beach	Orange	24	696 (1803)	
	Potters Ind., Inc.	Anaheim	Orange	24	696 (1803)	
	Ray-Lite Glass, Inc.	South Gate	Los Angeles	24	662 (1715)	6
Colorado	Pikes Peak Glass Co.	Colorado Springs	El Paso	38	41 (106)	2
	Rocky Mountain	Durango	LaPlata	14	4 (10)	2
Connecticut	Thermos Div., King Seeley Thermos Co.	Norwich	New London	41	127 (329)	
	Thermos Div., King Seeley Thermos Co.	South Windsor	Hartford	42	427 (1105)	
Delaware	Kaufman Glass Co.	Wilmington	New Castle	45	340 (881)	
Florida	Big Pine Glass	Big Pine Key	Monroe	50	19 (49)	2
Illinois	Erie Glass Mfg. Co.	Park Ridge	Cook	67	2197 (5690)	
	Johnson Glass	Chicago	Cook	67	2197 (5690)	6
	Owens Illinois	Chicago Heights	Cook	67	2197 (5690)	
	Peltier Glass Co.	Ottawa	LaSalle	71	37 (96)	8
	Reha Glass Co.	Chicago	Cook	67	2197 (5690)	
	Sellstrom Mfg.	Palatine	Cook	67	2197 (5690)	

TABLE A-1 (Continued)

State	Plant	City	County	AQCR	County Population Density, persons/km^2 (persons/mi^2)	Furnaces
Indiana	Canton Glass	Hartford City	Blackford	76	34 (88)	11
	Corning Glass Works	Bluffton	Wells	87	25 (65)	
	Indiana Glass Corp.	Dunkirk	Jay	76	23 (60)	9
	Indiana Glass Corp.	Dunkirk	Jay	76	23 (60)	9
	Owens-Illinois	Warsaw	Kosciuko	82	34 (89)	
	St. Clair Glass Works	Elwood	Madison	76	117 (303)	4
	Sinclair Glass	Hartford City	Blackford	76	34 (88)	11
Kentucky	Corning Glass Works	Danville	Boyle	102	43 (111)	
	Corning Glass Work	Harrodsburg	Mercer	102	24 (62)	
	GTE Sylvania, Inc.	Versailles	Westford	102	28 (73)	
	General Electric	Lexington	Fayette	102	239 (619)	
	General Electric	Sommerset	Pulaski	105	20 (52)	
	Venesian Art Glass	Catlettsburg	Boyd	103	123 (319)	
Louisiana	Owens-Illinois	Shreveport	Caddo	22	97 (251)	
Maryland	Owens-Illinois	Elkton	Cecil	114	56 (145)	
Massachusetts	American Optical	Southbridge	Worchester	118	162 (420)	
	American Optical	Southbridge	Worchester	118	162 (420)	
	Atlantic Optical Moulding	Dudley	Worchester	118	162 (420)	7
	Emerson & Cuming	Canton	Norfolk	119	594 (1538)	
	GTE Sylvania, Inc.	Danvers	Essex	119	493 (1277)	
	GTE Sylvania, Inc.	Ipswich	Essex	119	493 (1277)	
Michigan	B & J Optical	Lincoln Park	Wayne	123	1702 (4408)	

TABLE A-1 (Continued)

State	Plant	City	County	AQCR	County Population Density, persons/km^2 (persons/mi^2)	Furnaces
Mississippi	Cataphote	Jackson	Hinds	5	92 (238)	6
	General Electrick	Jackson	Hinds	5	92 (238)	
Missouri	Pittsburgh Corning Corp.	Sedalia	Pettis	138	19 (50)	3
New Hampshire	GTE Sylvania	Greenland	Hillsboro	121	76 (197)	
New Jersey	Chemglass, Inc.	Newfield	Gloucester	45	203 (525)	
	Fischer & Porter Co.	Vineland	Cumberland	149	92 (238)	
	Friedrich & Dummock, Inc.	Millville	Cumberland	149	92 (238)	
	Masden, Inc.	N. Bergen	Hudson	43	4907 (12,709)	
	National Glass & Plastics	Newfield	Gloucester	45	203 (525)	
	Owens-Illinois	Pennsauken	Camden	45	797 (2065)	
	Owens-Illinois	Vineland	Cumberland	149	92 (238)	
	Potters Ind., Inc.	Carlstadt	Bergen	43	1463 (3789)	
	Thermal American Fused Quartz	Montville	Morris	43	314 (813)	
	Westinghouse Electric Corp.	Bloomfield	Essex	43	2672 (7154)	3
	Wheaton Ind.	Millville	Cumberland	149	92 (238)	
New York	American Optical	Buffalo	Erie	161	406 (1052)	
	Bausch & Lomb	Rochester	Monroe	159	404 (1046)	
	Corning Glass Works	Corning	Steuben	163	27 (70)	
	Eastman Kodak Co.	Rochester	Monroe	159	404 (1046)	
	Gillinder Bros.	Port Jervis	Orange	160	101 (262)	5
	Kessler, Inc. (Warren)	Long Island	New York	43	25,337 (65,623)	2
	Super Glass Corp.	Brooklyn	Kings	43	14,132 (36,602)	15
	Swift Glass Corp.	Elmira	Chemung	163	94 (243)	
North Carolina	Potters Ind., Inc.	Apex	Johnston	166	29 (75)	

TABLE A-1 (Continued)

State	Plant	City	County	AQCR	County Population Density, persons/km^2 (persons/mi^2)	Furnaces
Ohio	Anchor Hocking	Bremen	Fairfield	176	55 (142)	
	Anchor Hocking	Canal Winchester	Fairfield	176	55 (142)	
	Anchor Hocking	Lancaster	Fairfield	176	55 (142)	
	Anchor Hocking	Lancaster	Fairfield	176	55 (142)	
	Brady Co., E.O.	Cleveland	Cuyahoga	174	1441 (3732)	
	Cambridge Glass	Cambridge	Guernsey	183	28 (73)	8
	Corning Glass Works	Greenville	Darke	173	32 (83)	3
	Crystal Art Glass	Cambridge	Guernsey	183	28 (73)	1
	Federal Glass Co.	Columbus	Franklin	176	591 (1531)	6
	General Electric	Bucyrus	Crawford	175	48 (124)	
	General Electric	Cleveland	Cuyahoga	174	1441 (3732)	
	General Electric	Logan	Hocking	182	19 (49)	
	General Electric	Niles	Trumble	178	144 (373)	
	General Electric	Niles	Trumble	178	144 (373)	
	Guernsey Glass Co.	Cambridge	Guernsey	183	28 (73)	3
	Holophane	Newark	Licking	176	60 (155)	2
	Imperial Glass Corp.	Bellaire	Belmont	181	58 (150)	9
	Interpace Corp.	Tiffin	Scioto	103	49 (127)	
	Libino Glass Labs.	Grand Rapids	Wood	124	55 (142)	5
	Lancaster Glass Corp.	Lancaster	Fairfield	176	55 (142)	6
	Owens-Illinois	Columbus	Franklin	176	591 (1531)	
	Owens-Illinois	Toledo	Lucas	124	539 (1396)	
	Potters Ind., Inc.	Cleveland	Cuyahoga	174	1441 (3732)	
	RCA Corp.	Circleville	Pickaway	176	30 (78)	
	Rodefer-Gleason Glass Co.	Bellaire	Belmont	181	58 (150)	5
	Techniglass, Inc.	Newark	Licking	176	60 (155)	1
	Variety Glass, Inc.	Cambridge	Guernsey	183	28 (73)	2
Oklahoma	Corning Glass Works	Muskogee				2
	Bartlett-Collins	Sapulpa	Creek	186	19 (48)	2
	Overmyer-Perram	Tulsa	Tulsa	186	268 (964)	2

TABLE A-1 (Continued)

State	Plant	City	County	AQCR	County Population Density, persons/km^2) (persons/mi^2)	Furnaces
West Virginia	Beaumont Co.	Morgantown	Monongalia	235	66 (171)	4
	Blenko Glass Co.	Milton	Cabell	103	144 (373)	
	Brockway Glass	Clarksburg	Harrison	235	66 (171)	6
	Brockway Glass	Parkersburg	Wood	179	88 (228)	1
	Champion Agate Co.	Pennsboro	Ritche	232	8 (21)	5
	Colonial Glass Co.	Weston	Lewis	232	17 (44)	1
	Corning Glass Works	Paden City	Tyler	179	15 (39)	
	Corning Glass Works	Martinsburg				1
	Corning Glass Works	Parkersburg	Wood	179	88 (228)	2
	Crescent Glass Co.	Wellsburg	Brooke	181	129 (334)	10
	Davis-Lynch Glass Co.	Star City	Monongalia	235	66 (171)	12
	Elite Co., Inc.	Cameron	Marshall	181	47 (122)	
	Erskine Glass & Mfg.	Wellsburg	Brooke	181	129 (334)	6
	Fenton Art Glass	Williamstown	Mingo	236	29 (75)	11
	Fostoria Glass Co.	Mounsville	Marshall	181	47 (122)	3
	Gentile Glass Co.	Star City	Monongalia	235	66 (171)	2
	Gentile Glass Co.	Star City	Monongalia	235	66 (171)	
	Gladding-Vitio-Agate Co.	Parkersburg	Wood	179	88 (228)	12
	Hamon Handcrafted Glass	Dunbar	Kanawha	234	95 (246)	3
	Harvey Ind.	Clarksburg	Harrison	235	66 (171)	7
	Kanawha Glass Co.	Dunbar	Kanawha	234	95 (246)	8
	Lewis County Glass	Jane Lew	Lewis	232	17 (44)	1
	Louie Glass Co.	Weston	Lewis	232	17 (44)	3
	Marble King	Paden City	Tyler	179	15 (39)	9
	Mid-Atlantic	Ellenboro	Ritchie	232	8 (21)	1
	Minners	Salem	Harrison	235	60 (171)	2
	Pennsboro Glass Co.	Pennsboro	Ritchie	232	8 (21)	1
	Pilgrim Glass Corp.	Ceredo	Cabell	103	144 (373)	8
	Rainbow Art Glass	Huntington	Cabel	103	144 (373)	7
	Scandia Glass Works	Kenova	Wayne	103	28 (73)	6
	Seneca Glass Co.	Morgantown	Monongalia	235	66 (171)	
	Earl Shelly Glass Co.	Huntington	Cabell	103	144 (373)	
	Viking Glass Co.	Huntington	Cabell	103	144 (373)	6
	Viking Glass Co.	New Martainsville	Wetzel	179	21 (54)	4
	West Virginia Glass Specialty	Weston	Lewis	232	17 (44)	
	Westinghouse Electric	Fairmont	Marion	235	75 (194)	3
	The Paul Wissmach Glass Co.Inc.	Paden City	Tyler	179	15 (39)	
Wisconsin	Pope Scientific, Inc.	Menomonee Falls	Waukesha	238	161 (418)	

TABLE A-1 (Continued)

State	Plant	City	County	AQCR	County Population Density, persons/km^2 (persons/mi^2)	Furnaces
Pennsylvania	Corning Glass Works	Bradford	McCain			1
	Corning Glass Works	State College	Centre	195	34 (88)	2
	Corning Glass Works	Wellsboro	Tioga	151	13 (34)	2
	Corning Glass Works	Charleroi				4
	Fischer & Porter Co.	Warminster	Bucks	45	261 (676)	
	General Electric	Bridgeville	Allegheny	197	842 (2181)	
	Haley Glass Co.	Greensburg	Westmoreland	197	142 (369)	
	Houze Glass Corp.	Point Marion	Fayette	197	75 (194)	1
	Jeannette Corp.	Jeannette	Westmoreland	197	142 (369)	4
	Jeannette Shade & Novelty Co.	Jeannette	Westmoreland	197	142 (369)	5
	Kopp Glass, Inc.	Pittsburgh	Allegheny	197	842 (2181)	
	Lenox Crystal	Mt. Pleasant	Westmoreland	197	142 (369)	
	Mayflower Glass	Latrobe	Westmoreland	197	142 (369)	2
	Millstein, J. H.	Jeannette	Westmoreland	197	142 (369)	
	Owens-Illinois	Pittston	Luzerne	151	147 (386)	
	Pennsylvania Glass Products	Pittsburgh	Allegheny	197	842 (2181)	
	Phoenix Glass Co.	Monaca	Beaver	197	180 (466)	8
	Pittsburgh Corning Corp.	Port Allegheny	McKean	178	20 (52)	3
	Schott Optical Glass Co.	Duryea	Luzerne	151	147 (386)	
	L. E. Smith Glass Co.	Mt. Pleasant	Westmoreland	197	142 (369)	7
	Victory Glass Co.	Jeannette	Westmoreland	197	142 (369)	
	Westmoreland Glass	Grapeville	Westmoreland	197	142 (369)	5
Rhode Island	Corning Glass Works	Central Falls	Providence	120	534 (1383)	
Texas	EMC Glass Corp.	Decatur	Wise	215	8 (21)	7
	Multicolor Glass	San Antonio	Bexar	217	258 (668)	2
	Potter Ind., Inc.	Brownwood	Brown	210	10 (26)	
Virginia	Corning Glass Works	Danville	Pittsylvania	222	259 (671)	8
Washington	Nuclear Pacific	Seattle	King	229	207 (536)	
	Penbarthy Electromelt Int., Inc.	Seattle	King	229	207 (536)	3

TABLE A-1. (Continued)

State	Plant	City	County	AQCR	County Population Density persons/km^2 (persons/mi^2)	Furnaces
West Virginia (Continued)	Pennsboro Glass Co.	Pennsboro	Ritchie	232	8 (21)	1
	Pilgrim Glass Corp.	Caredo	Cabell	103	144 (373)	8
	Rainbow Art Glass	Huntington	Cabel	103	144 (373)	7
	Scandia Glass Works	Kenova	Wayne	103	28 (73)	6
	Seneca Glass Co.	Morgantown	Monongalia	235	66 (171)	
	Earl Shelly Glass Co.	Huntington	Cabell	103	144 (373)	
	Viking Glass Co.	Huntington	Cabel	103	144 (373)	6
	Viking Glass Co.	New Martainsville	Wetzel	179	21 (54)	4
	West Virginia Glass Specialty	Weston	Lewis	232	17 (44)	
	Westinghouse Electric	Fairmont	Marion	235	75 (194)	3
	The Paul Wissmach Glass Co.Inc.	Paden City	Tyler	179	15 (39)	
Wisconsin	Pope Scientific, Inc.	Menomonee Falls	Waukesha	238	161 (418)	

APPENDIX B

EMISSIONS DATA

APPENDIX B

EMISSIONS DATA

Raw Materials Preparation and Handling

Five typical points for particulate emissions have been considered for the raw materials preparation and handling operations: (1) unloading and conveying, (2) crushing of cullet (scrap glass), (3) filling and emptying of storage bins, (4) weighing and mixing of batch, and (5) feeding of batch to glass melting furnace (batch charging). Source test data are summarized in Table B-1.

Emissions from the raw materials preparation and handling operation consist entirely of particulates from raw materials. In practice, only fugitive dust emissions should be considered, since particulate emissions remaining within the plant may constitute an OSHA health and safety consideration distinct from plant emissions. As discussed in the text, only particles below 100 micron are considered as contributing to fugitive dust emissions. Actual measurements of plant emissions from these operations are not available; however, personal observation indicates that there are no visible emissions from the batch house. Measurements of particulate emissions within a few plants are available from NEDS(9) and have been used to determine particulate emissions on a worst-case basis.

The average emission factors for the various raw material preparation and handling operations were taken to be the following, calculated on a worst-case basis.

		mg/kg	
1.	Handling	1500	± 100 %
2.	Crushing	<0.1	
3.	Storage	100	± 100%
4.	Mixing	310	± 100%
5.	Charging	<0.1	
		1910	± 100%

TABLE B-1. SUMMARY OF SOURCE TEST DATA FOR MATERIALS PREPARATION AND HANDLING(a)

Plant	Particulate Emissions Mg/yr	Particulate Emissions (Tons/yr)	Production Gg/yr	Production (Tons/yr)	Rate mg/kg (lb/ton)	Control Equipment	Operation
1(c)	1.80	(2)	0.28	(306)	6.54 (13.07)	fabric filter	raw material handling
2	12.70	(14)	12.70	(14,000)	1.00 (2)	none	raw material handling
3(c)	trace(b)		45.90	(50,600)	0	wet-scrubber	mixing
4	56.20	(62)	52.16	(57,500)	1.08 (2.16)	none	mixing
5	9.10	(10)	3.22	(3,560)	2.83 (5.62)	fabric filter	mixing
6	trace(b)		45.9	(50,600)	0	fabric filter	mixing

(a) Source NEDS(9) - All for flint glass.
(b) Trace <1.0 T/yr.
(c) Data from source test measurements.

Total annual emissions were based on 3.37 Tg of raw materials being processed to melt 1.39 Tg of glass, assuming that 48 percent of glass melted produced a saleable product. Furthermore, a 20 percent weight loss during melting, such as in the decomposition of Na_2CO_3, was also assumed. Stack heights for these and other plant operations were listed in Appendix C. They range from 2 m (6.5 feet) to 36 m (118 feet).

The accuracy is obtainable only for batch mixing where the sample mean is 1.0 mg/kg and the sample standard deviation is 1.1 mg/kg. The 95 percent confidence level is ± 1.78 mg/kg. The accuracy of engineering estimates are assumed to be ± 100 percent.

Glass Melting

Nitrogen Oxides

Measurements of NO_x emissions from NEDS$^{(9)}$ are listed in Table B-2. Emissions factors vary from 0.41 to 10.00 g/kg (0.81 to 20.00 lb/ton), which clearly reflect the wide range of operating conditions found in glass melting furnaces. The average emission factor of 4.25 g/kg (8.49 lb/ton) is based upon source test measurements from furnaces melting soda-lime glasses. Since the type of glass is not expected to significantly affect the NO_x emission rate, this emission factor is assumed to be representative of the entire industry. The average emission factor for soda-lime glass was determined by adding the average emission factors together and dividing by the number of values. Because of the sparcity of data, various point source measurements are used. Alternatively, the average is found by dividing the total emissions by total production was 2.19 g/kg (4.74 lb/ton). The difference is not significant because the standard deviation is 3.18 g/kg, and the 95 percent confidence level is ± 1.84 g/kg.

Standard deviations were determined by the following method.

$$\sigma = \left[\frac{1}{n} \sum_{i=1}^{n} (X_i - \mu)^2 \right]^{1/2}$$

TABLE B-2. NO_x EMISSIONS FROM PRESSED AND BLOWN GLASSWARE FURNACES

	Production		Emissions		Emission Factor		
	Gg/yr	(tons/yr)	Mg/yr	(tons/yr)	g/Kg	(lb/ton)	
Soda-Lime							
1[(a)]	23	(25,600)	232.2	(256)	10.00	(20.00)	
2[(a)]	4	(4,870)	31.7	(35)	7.19	(14.37)	
3[(a)]	4	(4,870)	31.7	(35)	7.19	(14.37	
4[(a)]	4	(4,870)	31.7	(35)	7.19	(14.37)	
5[(a)]	4	(4,870)	31.7	(35)	7.19	(14.37)	
6[(a)]	4	(4,870)	31.7	(35)	7.19	(14.37)	
7[(a)]	4	(4,870)	31.7	(35)	7.19	(14.37)	
TOTAL	47	(58,820)	422.7	(466)	7.59	(15.18)	(average)
8	78	(86,200)	31.7	(35)	0.41	(0.81)	
9	30	(32,900)	19.1	(21)	0.64	(1.28)	
10	17	(18,200)	19.1	(21)	1.15	(2.31)	
11	25	(27,400)	19.1	(21)	0.77	(1.53)	
12	17	(18,200)	19.1	(21)	1.15	(2.31)	
13	37	(41,200)	25.4	(28)	0.68	(1.36)	
14	12	(13,600)	19.1	(21)	1.54	(3.09)	
TOTAL	263	(267,520)	575.2	(634)	4.25	(8.49)	(average)

(a) Source - test measurement data

where: n = number of samples

X_i = sample value

μ = sample mean.

The confidence interval (CI) was determined by:

$$CI = \frac{t\sigma}{n^{1/2}}$$

where: t = "Student's t" variable for n-1 degrees of freedom.

Sulfur Oxides

Source test measuremnts of SO_x emissions from NEDS$^{(9)}$ are given in Table B-3. Only 5 measurements are available: 3 for soda-lime glass and 2 for borosilicate glass. The values for borosilicate must be due to oil firing since sulfate materials are not used to make this glass. The emission factors vary from 0.54 to 5.44 k/kg (1.09 to 10.87 lb/ton). The average emission factor of 2.80 g/kg (5.61 lb/ton) is based upon all of the measurement data since, in general, SO_x emissions will not be dependent upon the type of glass being melted. For the values given the standard deviation is calculated to be 1.41 g/kg, with the 95 percent confidence level ± 1.75 g/kg. The dependence of SO_x emissions on fuel oil used instead of natural gas is not clearly defined, but the increased use of oil, or other sulfur bearing fossil fuel, is expected to increase both the rate and amount of SO_x emissions.

TABLE B-3. SO_x EMISSIONS FROM PRESSED AND BLOWN GLASSWARE FURNACES

	Production		Emissions		Emission Factor		
	Gg/yr	(tons/yr)	Mg/yr	(tons/yr)	g/Kg	(lb/ton)	
Soda-Lime							
1[(a)]	126	(139,000)	9.98	(11)	2.95	(5.90)	
2	65	(72,000)	217.7	(240)	3.33	(6.67)	
3	8	(8,000)	9.98	(11)	1.75	(3.50)	
TOTAL	199	(219,000)	267.6	(295)	2.68	(5.36)	(average)
Borosilicate							
1[(a)]	3	(3,680)	1.81	(2)	0.54	(1.09)	
2[(a)]	3	(3,680)	18.14	(20)	5.44	(10.87)	
TOTAL	6	(7,360)	19.96	(22)	2.99	(5.98)	(average)
TOTAL FOR ALL	205	(226,360)	287.58	(317)	2.80	(5.61)	(average)

(a) Source test measurements.

Particulates

Source test measurements obtained from NEDS(9) are listed in Table B-4. Emission data are only available from furnaces melting soda lime and lead glasses. Only a single source test measurement was available for the lead glass. No data are available for borosilicate or opal glasses. Emission factors for soda-lime varied from 0.49 to 12.57 g/kg (0.97 to 25.14 lb/ton). The average emission factor for soda lime is 5.22 g/kg (10.44 lb/ton). The standard deviation is 4.7 g/kg and the 95 percent confidence interval is ± 2.25 g/kg.

Based on data supplied by glass manufacturers,(14,33) worst-case engineering calculations were made for borosilicate, opal, and lead glasses. The highest emission factor for borosilicate was taken as 25 g/kg (50 lb/ton), for opal glass 5 g/kg (10 lb/ton), and for lead glass 15 g/kg (30 lb/ton). The accuracy was taken as ± 100 percent.

An overall emission factor for particulates was taken to be 8.7 g/kg. It was determined as a weighted average of each of the above emission factors and the percentage of each type of glass melted.

Carbon Monoxide

Measurements of carbon monoxide emissions from glass melting furnaces are scarce, since this is not a major emission. High combustion temperatures and the presence of excess air do not favor its formation. It can form in glass melting furnaces because of incomplete combustion within long diffusion flames used to effect uniform heat release over the molten glass. When combustion is properly controlled, emissions are negligible. The three-source test measurements(9) available are for soda-lime glass. They are listed in Table B-5. The emission rate is not expected to vary much for other glass types. The average emission factor is 0.10 g/kg (0.19 lb/ton). The standard deviation is 0.045 g/kg with a 95 percent confidence level of 0.10 g/kg.

TABLE B-4. PARTICULATE MEISSIONS FROM PRESSED AND BLOWN GLASSWARE FURNACES

	Production		Emissions		Emission Factor		
	Gg/yr	(tons/yr)	Mg/yr	(tons/yr)	g/kg	(lb/ton)	
Soda-Lime							
1	38	(42,000)	38.1	(42)	1	(2.00)	
2	59	(64,900)	145.2	(160)	2.4	(4.93)	
3	78	(86,200)	38.1	(42)	0.49	(0.97)	
4	8	(8,570)	49.9	(55)	6.29	(12.57)	
5	8	(8,570)	99.8	(110)	12.57	(25.14)	
6	10	(10,500)	74.4	(82)	7.84	(15.69)	
7	8	(8,570)	92.5	(102)	11.66	(23.31)	
8	16	(17,500)	31.8	(35)	2.00	(4.00)	
9	4	(4,380)	49.9	(55)	12.56	(25.11)	
10	30	(32,900)	62.6	(69)	2.10	(4.19)	
11	15	(16,400)	8.2	(9)	0.55	(1.10)	
12	29	(32,000)	44.5	(49)	1.53	(3.06)	
13	13	(14,000)	158.8	(175)	12.50	(25.0)	
14	18	(19,400)	14.5	(16)	0.82	(1.65)	
15	5	(5,090)	20.9	(23)	12.56	(25.11)	
16	37	(41,200)	194.1	(214)	5.19	(10.39)	
17	48	(52,500)	71.7	(79)	1.50	(3.01)	
18	65	(72,000)	127.0	(140)	1.94	(3.89)	
19	7	(8,000)	26.3	(29)	3.62	(7.25)	
TOTAL	496	(545,220)	1357.2	(1496)	5.22	(10.44)	(average)
Lead							
1	5	(5,090)	2.09	(23)	4.52	(9.04)	

TABLE B-5. CO EMISSIONS FROM PRESSED AND BLOWN GLASSWARE

	Production[a]		Emissions		Emission Factor		
	Gg/yr	(tons/yr)	Mg/yr	(tons/yr)	g/kg	(lb/ton)	
1	78	(86,200)	4.5	(5)	0.06	(0.12)	
2	12	(13,600)	1.8	(2)	0.15	(0.29)	
3	37	(41,200)	2.7	(3)	0.09	(0.15)	
TOTAL	127	(141,000)	9.0	(10)	0.10	(0.19)	(average)

(a) Soda Lime Glass

Hydrocarbons

Source test measurements of hydrocarbon emissions are also limited. Formation occurs for the same reasons as cited for carbon monoxide. These emissions are listed in Table B-6. Emission factors vary from 0.02 to 0.27 g/kg (0.05 to 0.55 lb/ton). The average emission factor is 0.15 g/kg (0.31 lb/ton). The amount of hydrocarbon emission is not expected to be significantly affected by the type of glass melted. The standard deviation is 0.09 g/kg, and the 95 percent confidence interval is ± 0.15 g/kg.

Fluorides

No source test data was available for fluoride emissions from glass melting furnaces (opal, borosilicate and lead glasses). Based upon information supplied by a glass manufacturer(33) and the open literature (15, 16, 17) a worst-case emission factor of 10 g/kg (20 lb/ton) of fluoride (as F^-) was assumed. The accuracy was taken as ± 100 percent.

Selenium

No source test measurements are available for selenium emissions from soda lime glass furnaces. Selenium is used as a decolorizer to neutralize the tint from transition metal oxide contaminants such as iron. Approximately 0.36 Gg (395 tons) of selenium are consummed annually in the U.S., of which an estimated 5 percent (0.0186 g) is used by the pressed and blown glass industry (0.06 Gg). Using a worst-case assumption, half of the selenium used is volatilized and emitted from the glass melting furnace, giving an emission rate of 0.002 g/kg. The accuracy of this calculation is taken as ± 100 percent.

Forming and Finishing

Few point source test measurements are available on emissions from the forming and finishing operations. Therefore, engineering calculations considering worst-case situations are used to determine the severity of emissions from these parts of the manufacturing process.

TABLE B-6. HC EMISSIONS FROM PRESSED AND BLOWN GLASSWARE

	Production(a)		Emissions		Emission Factor		
	Gg/yr	(tons/yr)	Mg/yr	(tons/yr)	g/kg	(lb/ton)	
1	78	(86,200)	8.2	(9)	0.10	(0.21)	
2	30	(32,900)	4.5	(5)	0.15	(0.30)	
3	17	(18,200)	4.5	(5)	0.27	(0.55)	
4	25	(27,400)	4.5	(5)	0.18	(0.37)	
5	17	(18,200)	4.5	(5)	0.27	(0.55)	
6	37	(41,200)	0.9	(1)	0.02	(0.05)	
7	13	(13,600)	0.9	(1)	0.07	(0.15)	
TOTAL	217	(237,700)	28.1	(31)	0.15	(0.31)	(average)

(a) Soda Lime Glass

Forming

During forming, an emulsion containing oil or silicone and water is sprayed onto the molds, gob shears, and delivery chutes. From 1 to 3 g of liquid are sprayed into a mold each time an article is formed. The oil:water mixture is normally 1:125.

Three measurements were reported(a) for hydrocarbon emissions from forming operations, and were listed in Table B-7. The average emission rate was 0.06 g/kg (0.11 lb/ton, and is higher than that determined by engineering calculation (0.035 g/kg) for forming glass containers(52). For an emission factor of 0.06 g/kg, the standard deviation is calculated to be 0.26 g/kg, with a 95 percent confidence interval of ± 0.06 g/kg.

Treatment

Assuming that 25 percent of all pressed and blown glassware produced receives a surface treatment to improve resistance to scratching and to facilitate handling, by subjecting the glass to a tin or titanium chloride vapor, emissions will consist of metal oxide, hydrated metal chloride particulates, and HCl. Approximately 60 weight percent of the total metal chloride input is released (14% metal oxide, 27% hydrated metal chloride and 21% HCl). Emission rates are estimated to be 0.02 g/kg (0.03 lb/ton) of tin chloride, 0.03 g/kg (0.06 lb/ton) of hydrated tin chloride, and 0.02 g/kg (0.05 lb/ton) of HCl. Accuracy of the data is taken at ± 100 percent.

Annealing

No reliable emission data are available for gas-fired annealing lehrs; therefore, emission factors are estimated from other data on gas combustion. A modern recirculating air-type lehr consumes 11 to 17 m^3/hr (400 cfh to 600 cfh) when annealing 91 Gg (100 tons of glass per day. Lehrs of older design can consume 34 to 57 m^3/hr (1200 cfh to 2000 cfh)(51). On a worst-case basis (57 m^3/hr would require 0.0062 m^3/kg of glass produced. For a plant producing 319 Mg/day (352 ton/day) this would amount to 91 m^3/hr. With a heating value of natural gas (1000 Btu/cf or 37.3 million joules/m^3) this amounts to

0.93 million joules per second or about 0.23 million joules per kg of glass (200,000 Btu/ton).

Using tests on gas-fired burners(53), emission data was determined as shown in Table B-8. Converting these on a basis of 0.24 million joules/kg of glass gave the emission factors for annealing shown in Table B-9.

Decorating

Tableware, artware, and novelties are sometimes decorated with vitrifiable glass enamels or organic materials. Emissions are derived from organic solvents and binders used in the coatings. Estimating that 30 percent of all pressed and blown tableware and art glass have decorative coatings, about 100 Gg (110,200 tons) of glassware are decorated annually. Only one source measurement is available (0.02 g/kg or 0.05 lb/ton). Using 4.5 g/kg (9.0 lb/ton) as a worst case, the total uncontrolled annual emissions will be 0.45 Gg (496 tons).

Frosting of Light Bulbs

While no information is available on atmospheric emissions from frosting operations, data are available(24) on water pollution. Wastewater comes from both rinsing and scrubbing operations. The reported pollutant level is 9.6 g/kg (1.92 lb/ton) for fluorides (HF) and 2.2 g/kg (4.4 lb/ton) for ammonia (NH_3). A worst-case calculation assumes that half the effluent loading is from the scrubbing water and that the scrubber is performing at 80 percent efficiency. The amount of frosted light bulbs produced is estimated at 90.7 Gg (100,000 tons). The controlled air emission factors are then 0.96 g/kg (1.92 lb/ton) for HF and 0.22 g/kg (0.44 lb/ton) for NH_3.

Acid Cleaning

While no air sampling data are available, information has been reported(24) on fluorides in wastewater from these operations. The rinse step and scrubber generate wastewater containing fluorides at a level of 1.8 g/kg (3.6 lb/ton). Considering a worst case that half of the fluoride is from the scrubber and that the scrubber operates at 80 percent efficiency, the controlled air emission rate for HF will be 0.18 g/kg (0.36 lb/ton). Assuming total product of picture tubes is 90.7 Gg (100,000 tons) then the total annual emissions of HF would be 16 Mg (18 tons).

TABLE B-7. HYDROCARBON EMISSIONS FROM FORMING PRESSED AND BLOWN GLASSWARE

	Production		Emissions		Emission Factor		
Case No.	Gg/yr	(tons/yr)	Mg/yr	(tons/yr)	g/kg	(lb/ton)	
1	27	(30,000)	4.5	(5)	0.17	(0.33)	
2	23	(25,000)	trace(a)		0		
3	1	(1,600)	trace(a)		0		
Total	51	(54,600)	4.5	(5)	0.06	(0.11)	(average)

(a) <0.01 T/yr.

APPENDIX C

STACK HEIGHTS FROM THE VARIOUS SEGMENTS OF GLASSMAKING PROCESS

TABLE C-1. TYPICAL STACK HEIGHTS OF BATCH-HANDLING OPERATIONS FOR SODA/LIME GLASS

<40 m		>40 m	
No. of Stacks	Height, m	No. of Stacks	Height, m
1	2		
2	5		
1	9		
1	13		
1	14		
1	23		
2	24		
1	36		
Total No. of Stacks	10	Total No. of Stacks	0
Average	16	Average	0
Median	14	Median	0

TABLE C-2. TYPICAL STACK HEIGHTS FOR MELTING OPERATIONS OF GLASS FURNACES

<40 m		>40 m	
No. of Stacks	Height, m	No. of Stacks	Height, m
	Soda Lime		
1	8	8	41
1	9	1	44
1	12	3	46
6	13	1	49
6	14	1	51
2	15	2	53
2	16		
1	17		
4	20		
3	21		
1	22		
2	23		
5	24		
1	27		
2	32		
1	33		
1	35		
1	37		
Total No. of Stacks	40	Total No. of Stacks	16
Average	19	Average	45
Median	20	Median	44

TABLE C-2. (Continued)

<40 m		>40 m	
No. of Stacks	Height, m	No. of Stacks	Height, m
Borosilicate			
2	11	7	41
1	21	1	49
2	27		
1	35		
Total No. of Stacks	6	Total No. of Stacks	8
Average	22	Average	42
Median	23	Median	45
Lead			
Total No. of Stacks	0	Total No. of Stacks	7
Average	0	Average	42
Median	0	Median	43
Total Industry			
No. of Stacks	46	No. of Stacks	31
Average	19	Average	44
Median	23	Median	47

TABLE C-3. TYPICAL STACK HEIGHTS FOR FORMING OPERATIONS

<40 m		>40 m	
No. of Stacks	Height, m	No. of Stacks	Height, m
	Soda Lime		
1	13	1	41
1	15		
Total No. of Stacks	2	Total No. of Stacks	1
Average	14	Average	41
Median	-	Median	41
	Lead		
2	15		
1	21		
1	28		
1	38		
Total No. of Stacks	5	Total No. of Stacks	0
Average	23	Average	0
Median	21	Median	0

TABLE C-4. TYPICAL STACK HEIGHTS FOR ANNEALING OPERATIONS OF BOROSILICATE GLASS

<40 m		>40 m	
No. of Stacks	Height, m	No. of Stacks	Height, m
1	12		
Total No. of Stacks	1	Total No. of Stacks	0
Average	12	Average	0
Median	12	Median	0

TABLE C-5. TYPICAL STACK HEIGHTS FOR DECORATING OPERATIONS OF SODA/LIME GLASS

<40 m		>40 m	
No. of Stacks	Height, m	No. of Stacks	Height, m
1	11		
1	12		
Total No. of Stacks	2	Total No. of Stacks	0
Average	12	Average	0
Median	-	Median	0

TABLE C-6. TYPICAL STACK HEIGHTS FOR TREATMENT OPERATIONS OF SODA/LIME GLASS

<40 m		>40 m	
No. of Stacks	Height, m	No. of Stacks	Height, m
3	13		

Total No. of Stacks	3	Total No. of Stacks	0
Average	13	Average	0
Median	13	Median	0

APPENDIX D

STATE LISTING OF TOTAL EMISSIONS AS OF 1972

TABLE D-1. STATE LISTING OF TOTAL EMISSIONS AS OF 1972

State	Mass of emissions, 1000 kg/yr (upper entry) Percent of U.S. totals (lower entry)				
	Particulate	SO_2	NO_x	Hydrocarbons	CO
1 ALABAMA	2002000.0 1.53000	1220000.0 1.91000	261600.0 2.27000	342100.0 1.29000	372600.0 2.04000
2 ALASKA	16340000.0 12.50000	222600.0 0.34700	31990.0 0.27700	140800.0 0.53200	472200.0 2.59000
3 ARIZONA	3265000.0 2.49000	200200.0 0.31100	75100.0 0.65100	171100.0 0.64700	178300.0 0.97800
4 ARKANSAS	1619000.0 1.24000	205400.0 0.31900	77310.0 0.67000	281700.0 1.07000	225800.0 1.24000
5 CALIFORNIA	5675000.0 4.33000	2557000.0 3.98000	796800.0 6.91000	1914000.0 7.24000	1987000.0 10.90000
6 COLORADO	3156000.0 2.41000	473300.0 0.73600	116800.0 1.01000	294400.0 1.11000	105800.0 0.57900
7 CONNECTICUT	365600.0 0.27900	1227000.0 1.91000	152200.0 1.32000	259400.0 0.98100	92690.0 0.50800
8 DELAWARE	130200.0 0.09930	420700.0 0.65500	45720.0 0.39600	77510.0 0.29300	24580.0 0.13500
9 FLORIDA	2430000.0 1.86000	1755000.0 2.73000	410300.0 3.56000	536200.0 2.03000	3502000.0 19.20000
10 GEORGIA	2331000.0 1.78000	1635000.0 2.54000	294200.0 2.55000	526700.0 1.99000	705400.0 3.86000
11 HAWAII	251200.0 0.19200	232000.0 0.36100	40790.0 0.35400	62720.0 0.23700	84750.0 0.46400
12 IDAHO	2430000.0 1.85000	59140.0 0.09200	33220.0 0.28800	163600.0 0.61900	518300.0 2.84000
13 ILLINOIS	3584000.0 2.74000	3714000.0 5.78000	665100.0 5.77000	1343000.0 5.08000	412500.0 2.26000
14 INDIANA	2202000.0 1.68000	3036000.0 4.72000	414400.0 3.59000	675100.0 2.55000	182100.0 0.99900
15 IOWA	2579000.0 1.97000	397400.0 0.61800	137700.0 1.19000	400800.0 1.52000	90720.0 0.49700
16 KANSAS	3358000.0 2.56000	225000.0 0.35000	109900.0 0.95300	742800.0 2.81000	174600.0 0.95800
17 KENTUCKY	1854000.0 1.42000	1627000.0 2.53000	302000.0 2.62000	274600.0 1.04000	219300.0 1.20000

TABLE D-1. (Continued)

State	Mass of emissions, 1000 kg/yr (upper entry) Percent of U.S. totals (lower entry)				
	Particulate	SO_2	NO_x	Hydrocarbons	CO
18 LOUISIANA	1651000.0 1.26000	585800.0 0.91100	219000.0 1.90000	1741000.0 6.58000	437400.0 4.66000
19 MAINE	1038000.0 0.79200	773700.0 1.20000	54270.0 0.47000	71970.0 0.27200	61430.0 0.33600
20 MARYLAND	657300.0 0.50200	1352000.0 2.10000	215100.0 1.86000	302300.0 1.14000	163400.0 0.89400
21 MASSACHUSETTS	802700.3 0.61300	3840000.0 5.97000	322300.0 2.79000	463100.0 1.75000	190400.0 1.04000
22 MICHIGAN	2804000.0 2.14000	3513000.0 5.46000	548000.0 4.75000	734000.0 2.78000	299400.0 1.64000
23 MINNESOTA	3056000.0 2.33000	846800.0 1.32000	185000.0 1.60000	388000.0 1.47000	150700.0 0.82500
24 MISSISSIPPI	1490000.0 1.14000	280300.0 0.43600	87010.0 0.75400	350200.0 1.32000	228200.0 1.25000
25 MISSOURI	2839000.0 2.17000	1259000.0 1.96000	287500.0 2.49000	588400.0 2.22000	268500.0 1.47000
26 MONTANA	4975000.0 3.80000	177000.0 0.27500	34650.0 0.30000	174200.0 0.65800	230500.0 1.26000
27 NEBRASKA	3049000.0 2.33000	137100.0 0.21300	50940.0 0.44200	255600.0 0.96600	59590.0 0.32600
28 NEVADA	3155000.0 2.41000	263100.0 0.40900	58500.0 0.50700	36140.0 0.13700	28700.0 0.15700
29 NEW HAMPSHIRE	326500.0 0.24900	325800.0 0.50700	36060.0 0.31300	44430.0 0.16800	30200.0 0.16500
30 NEW JERSEY	815800.0 0.62300	2922000.0 4.55000	323400.0 2.80000	786600.0 2.97000	281400.0 1.54000
31 NEW MEXICO	3548000.0 2.71000	441400.0 0.68700	109800.0 0.95200	310200.0 1.17000	49400.0 0.27100
32 NEW YORK	2704000.0 2.06000	5137000.0 7.99000	721400.0 6.25000	1353000.0 5.11000	551600.0 3.02000
33 N CAROLINA	2203000.0 1.68000	2298000.0 3.58000	338400.0 2.93000	465100.0 1.76000	371500.0 2.03000
34 N DAKOTA	2854000.0 2.18000	328700.0 0.51100	61110.0 0.53000	73930.0 0.28000	22340.0 0.12200
35 OHIO	3054000.0 2.33000	4062000.0 6.32000	785800.0 6.81000	1244000.0 4.70000	482700.0 2.64000
36 OKLAHOMA	2276000.0 1.74000	163400.0 0.25400	130000.0 1.13000	674700.0 2.55000	200800.0 1.10000
37 OREGON	2885000.0 2.20000	372500.0 0.57900	62710.0 0.54400	204800.0 0.77400	304900.0 1.67000

TABLE D-1. (Continued)

State	Mass of emissions, 1000 kg/yr (upper entry) Percent of U.S. totals (lower entry)				
	Particulate	SO_2	NO_x	Hydrocarbons	CO
38 PENNSYLVANIA	3132000.0 2.39000	5673000.0 8.72000	782200.0 6.78000	1331000.0 5.03000	527000.0 2.88000
39 RHODE ISLAND	113200.0 0.08640	519900.0 0.80900	38760.0 0.33600	93730.0 0.35400	29370.0 0.16100
40 S CAROLINA	1209000.0 0.92300	1076000.0 1.67000	146300.0 1.27000	260500.0 0.98500	483900.0 2.65000
41 S DAKOTA	2861000.0 2.18000	69420.0 0.10800	18560.0 0.16100	91110.0 0.34400	23480.0 0.12900
42 TENNESSEE	1789000.0 1.37000	1307000.0 2.03000	264100.0 2.29000	340900.0 1.29000	200300.0 1.10000
43 TEXAS	9302000.0 7.10000	1817000.0 2.83000	693500.0 6.03000	4139000.0 15.60000	1501363.0 8.24000
44 UTAH	2461000.0 1.88000	285400.0 0.44400	48410.0 0.42000	112800.0 0.42600	46940.0 0.25600
45 VERMONT	292100.0 0.22300	112600.0 0.17500	13710.0 0.11900	25460.0 0.09640	14190.0 0.07770
46 VIRGINIA	1607000.0 1.23000	1388000.0 2.16000	197600.0 1.71000	415200.0 1.57000	235100.0 1.29000
47 WASHINGTON	2204000.0 1.68000	626400.0 0.97500	126300.0 1.09000	361800.0 1.37000	425500.0 2.33000
48 W VIRGINIA	1261000.0 0.96200	1455000.0 2.26000	306500.0 2.66000	172800.0 0.65300	435100.0 2.38000
49 WISCONSIN	2180000.0 1.66000	1216000.0 1.89000	231300.0 2.00000	362600.0 1.37000	161300.0 0.88300
50 WYOMING	2851000.0 2.18000	513000.0 0.79800	70570.0 0.61200	275200.0 1.04000	20870.0 0.11400
US TOTALS	131000000.0	64300000.0	11500000.0	26400000.0	18300000.0

APPENDIX E

Conversion Factors

TABLE E-1. CONVERSION FACTORS

To Convert From	To	Multiply By
Btu	joule (J)	1.055×10^{3}
degree Fahrenheit (F)	degree Celsium (C)	$t^{o}_{C} = (t^{o}_{F} - 32)/1.8$
foot (ft)	meter (m)	3.048×10^{-1}
$foot^{3}$ (ft^{3})	$meter^{3}$ (m^{3})	2.832×10^{-2}
inch (in.)	meter (m)	2.540×10^{-2}
$mile^{2}$ (mi)	$meter^{2}$ (m^{2})	2.590×10^{6}
pound (mass, lb)	kilogram (kg)	4.536×10^{-1}
ton (short)	gigagram (Gg)	9.072×10^{-4}

PREFIXES

Prefix	Symbol	Multiplication Factor	Example
tera	T	10^{12}	$1\ Tg = 1 \times 10^{12}\ g$
giga	G	10^{9}	$1\ Gg = 1 \times 10^{9}\ g$
mega	M	10^{6}	$1\ Mg = 1 \times 10^{6}\ g$
kilo	k	10^{3}	$1\ km = 1 \times 10^{3}$
milli	m	10^{-3}	$1\ mm = 1 \times 10^{-3}\ m$
micro	μ	10^{-6}	$1\ \mu m = 1 \times 10^{-6}\ m$